Blood Vascular and Blood Flow Magnetic Resonance Imaging

혈관 및 혈류 자기공명영상

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Sung-Hong Park
Department of Bio and Brain Engineering
Korea Advanced Institute of Science and Technology

Contents

- Blood Vascular MRI
- Blood Flow MRI

What is the difference between blood and other tissues?

- Moving
  - Time-of-flight (TOF) angiography : inflow enhancement
  - Phase Contrast (PC) angiography : subtraction of images acquired with flow encoding and flow compensation
- Circulating
  - Contrast Enhanced (CE) angiography : injection of Gd-based contrast agent and dynamic acquisition of gradient echo images with very shortest TR/TE ($\leq$ 5ms) and low flip angle
- Deoxyhemoglobin in venous blood (paramagnetic)
  - BOLD Venography (Susceptibility-Weighted Imaging)

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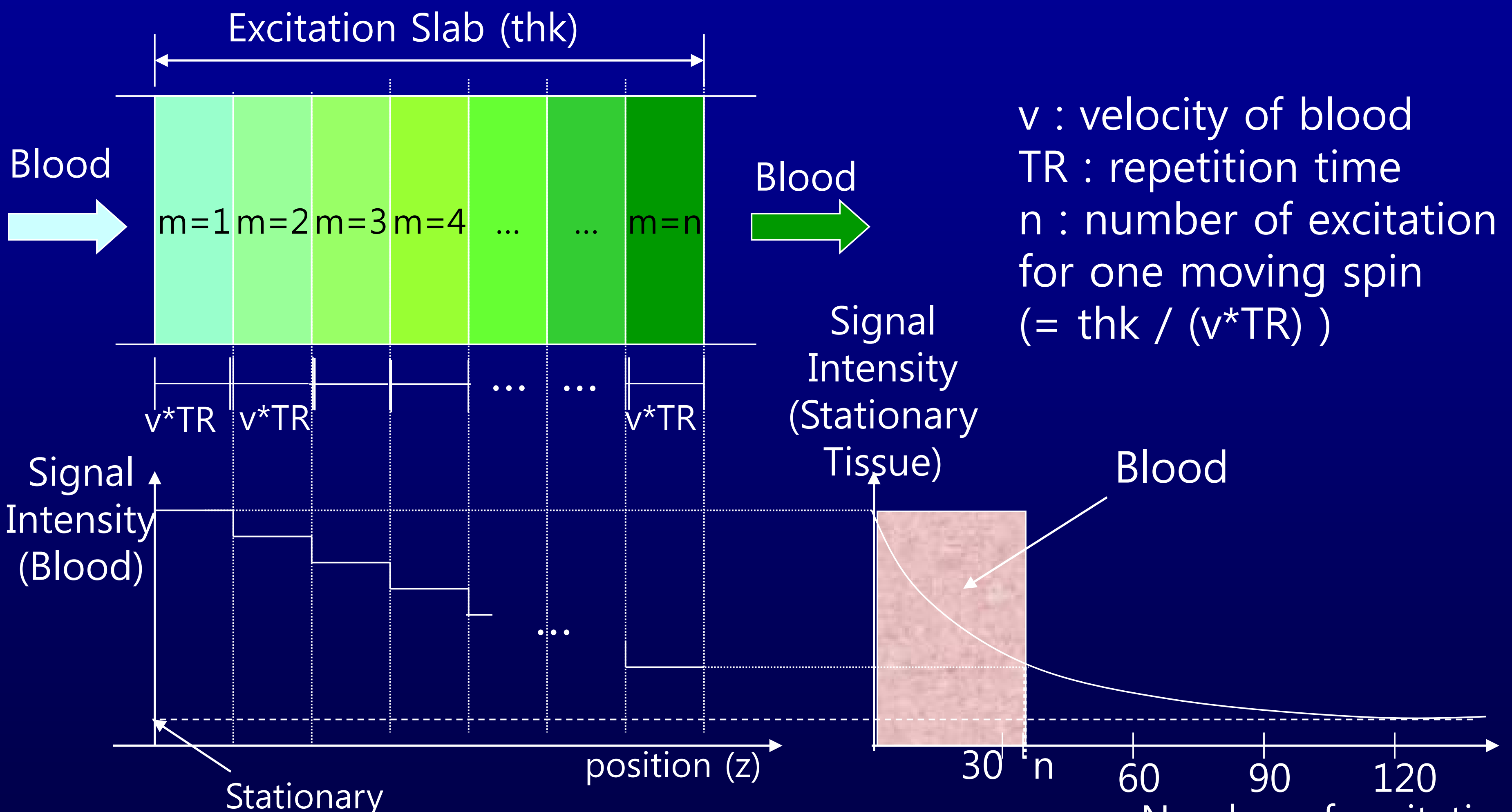
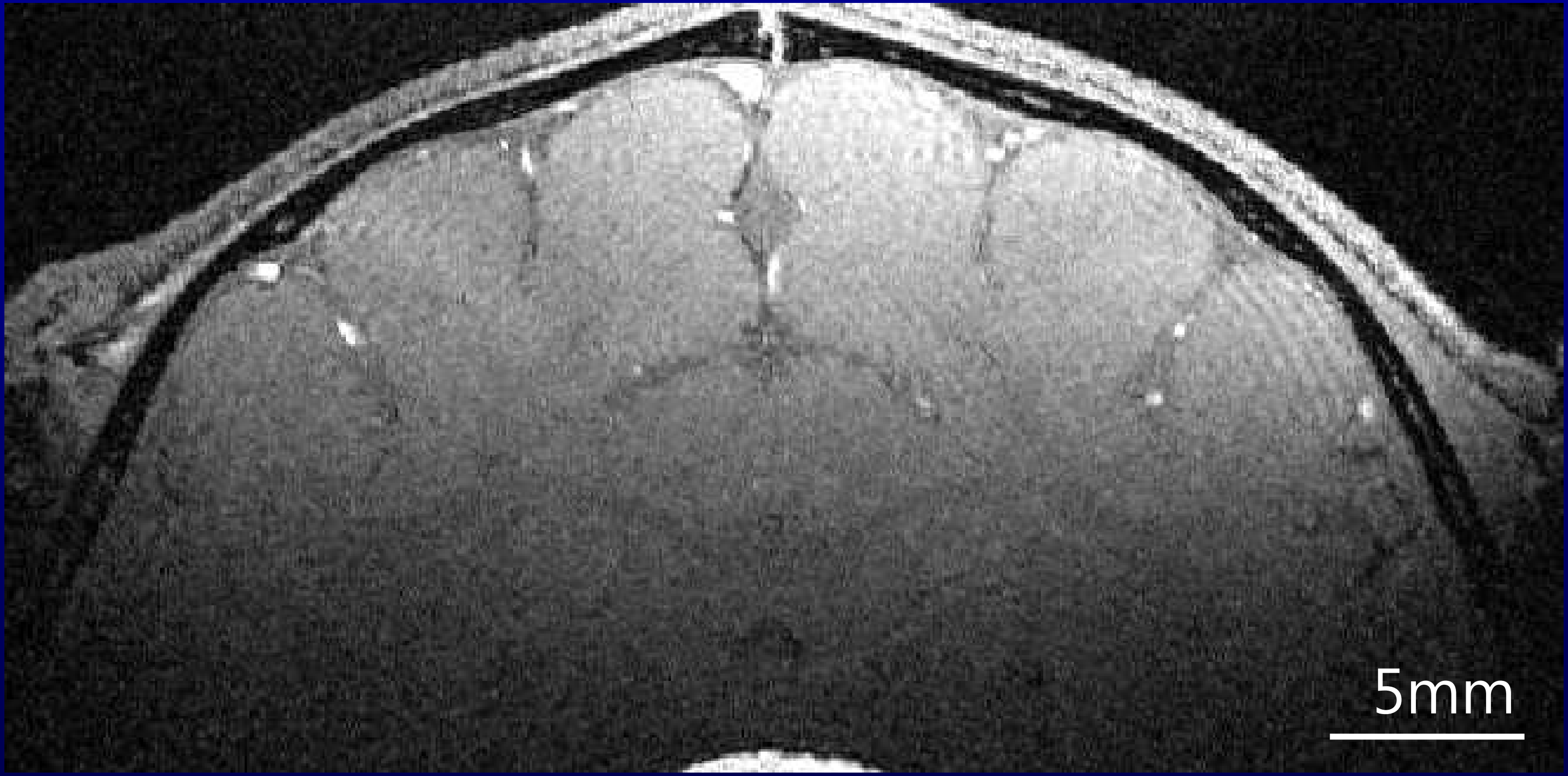
Time-of-flight (TOF) Angiography
(2) Inflow Enhancement

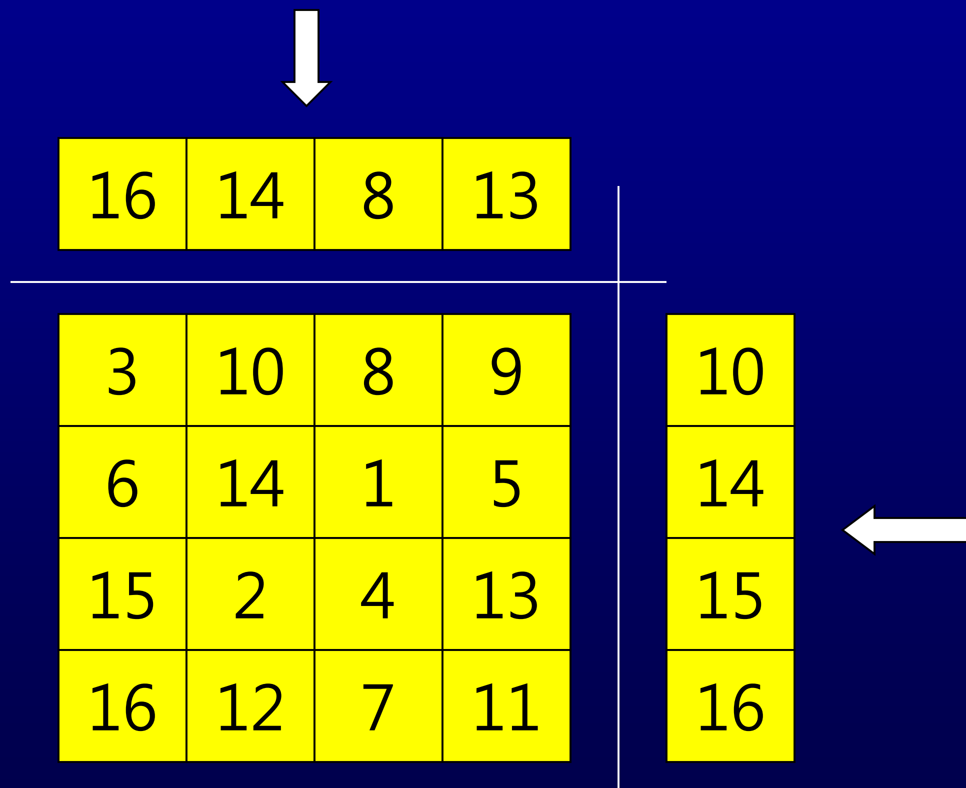


For the stationary tissue, n → ∞

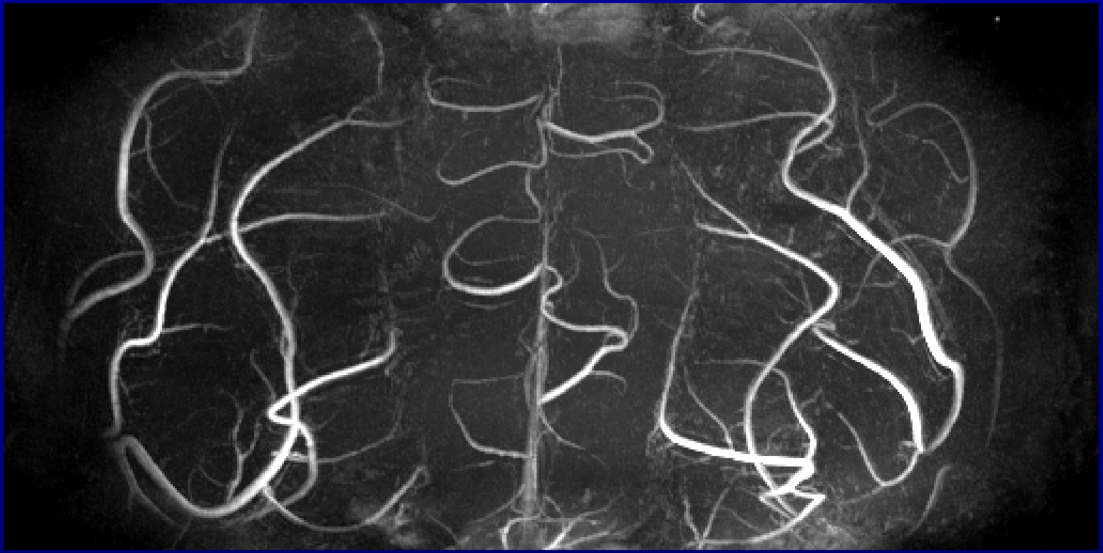
Time-of-flight (TOF) Angiography (3)
3D Base Image (Cat Brain)

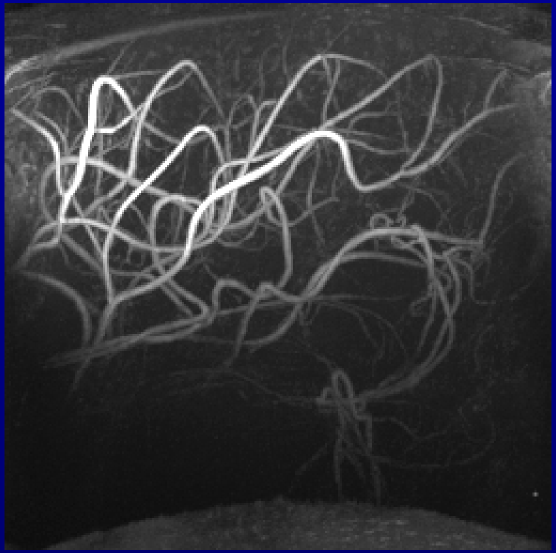


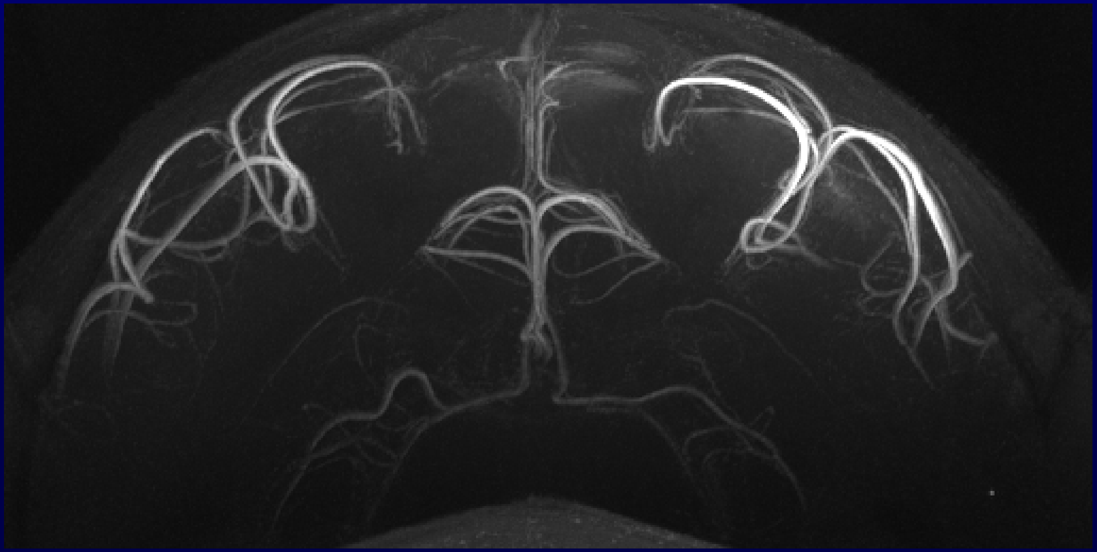
Time-of-flight (TOF) Angiography (4)
Maximum Intensity Projection (MIP)



TOF MR Angiography at 9.4T (Cat)

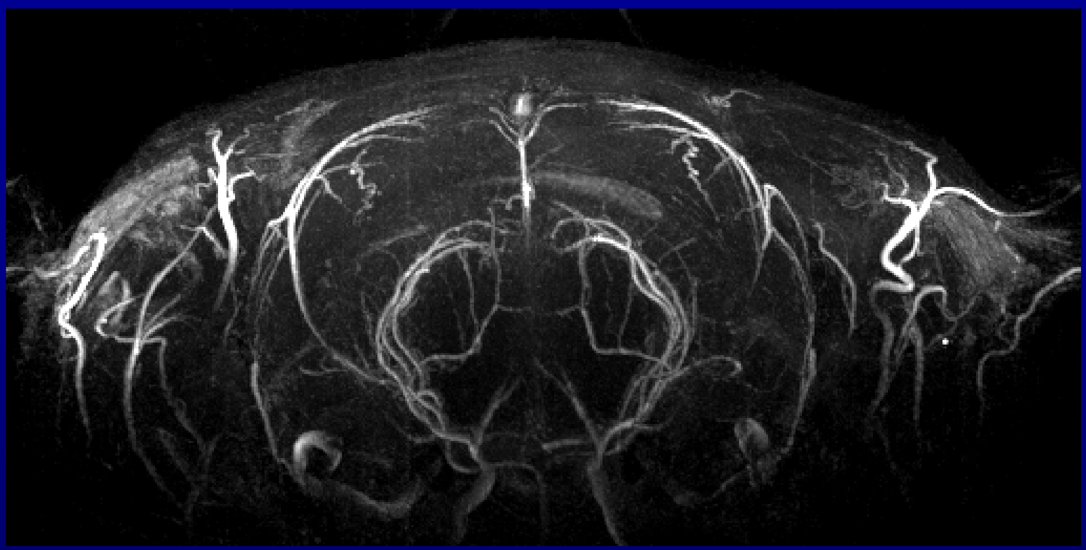


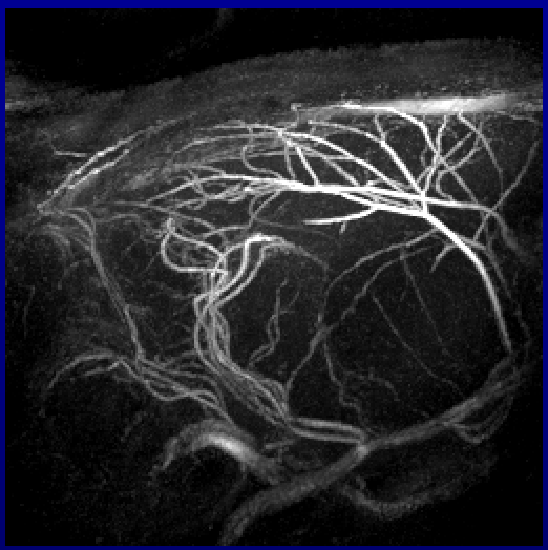




TR/TE:50/3.6 (ms)
FOV : 4x2x2 (cm^3)
Mat : 384x192x192
→ 512x256x256
FA : around 20°
1st order flow com. (S,R)
MTC

TOF MR Angiography at 9.4T (Rat)





TR/TE:50/3.6 (ms)
FOV : 3x1.5x1.5 (cm^3)
Mat : 384x192x192
→ 512x256x256
FA : around 20°
1^{st} order flow com. (S,R)
MTC

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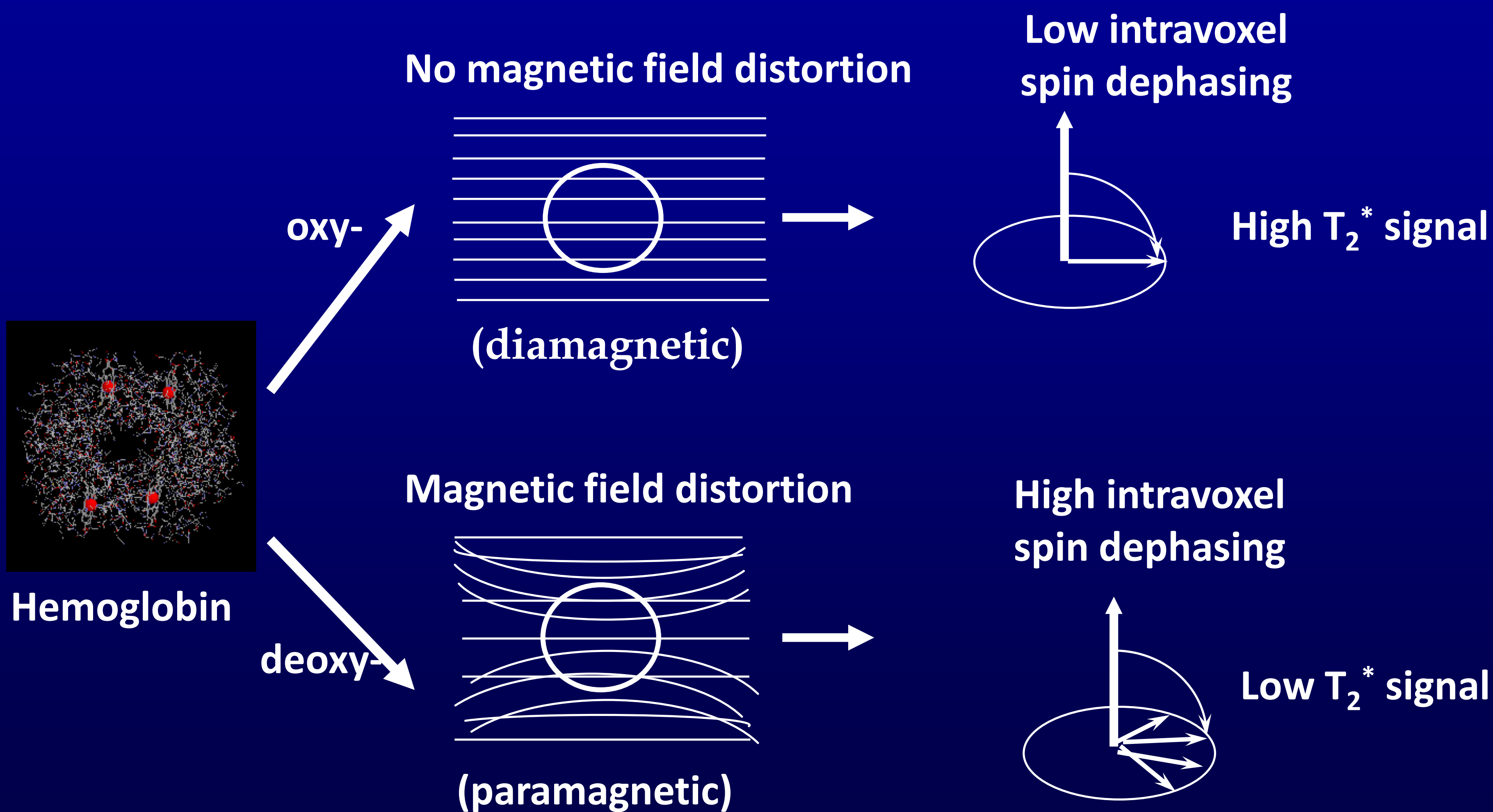
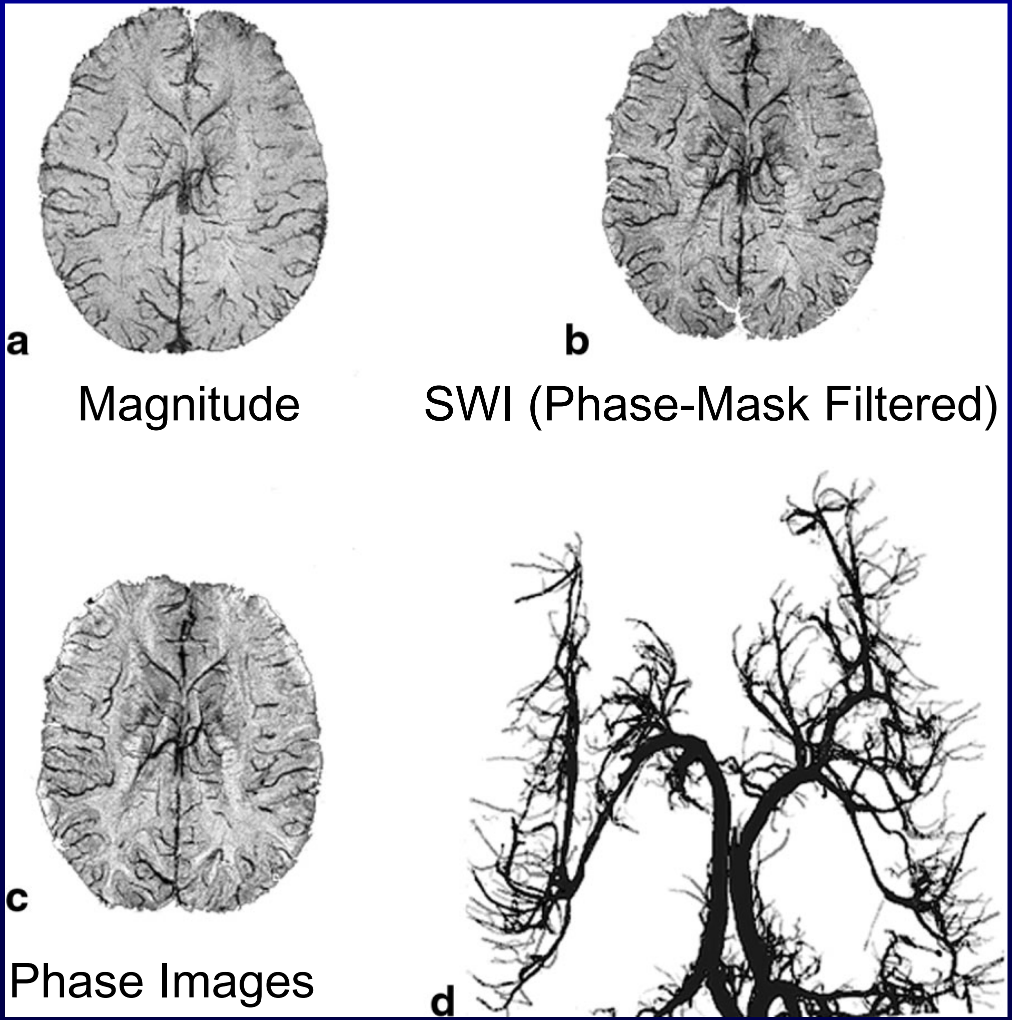
Magnetic properties of oxy-/deoxy- Hemoglobin (Hb)



Susceptibility-Weighted Imaging (SWI)



Magnitude

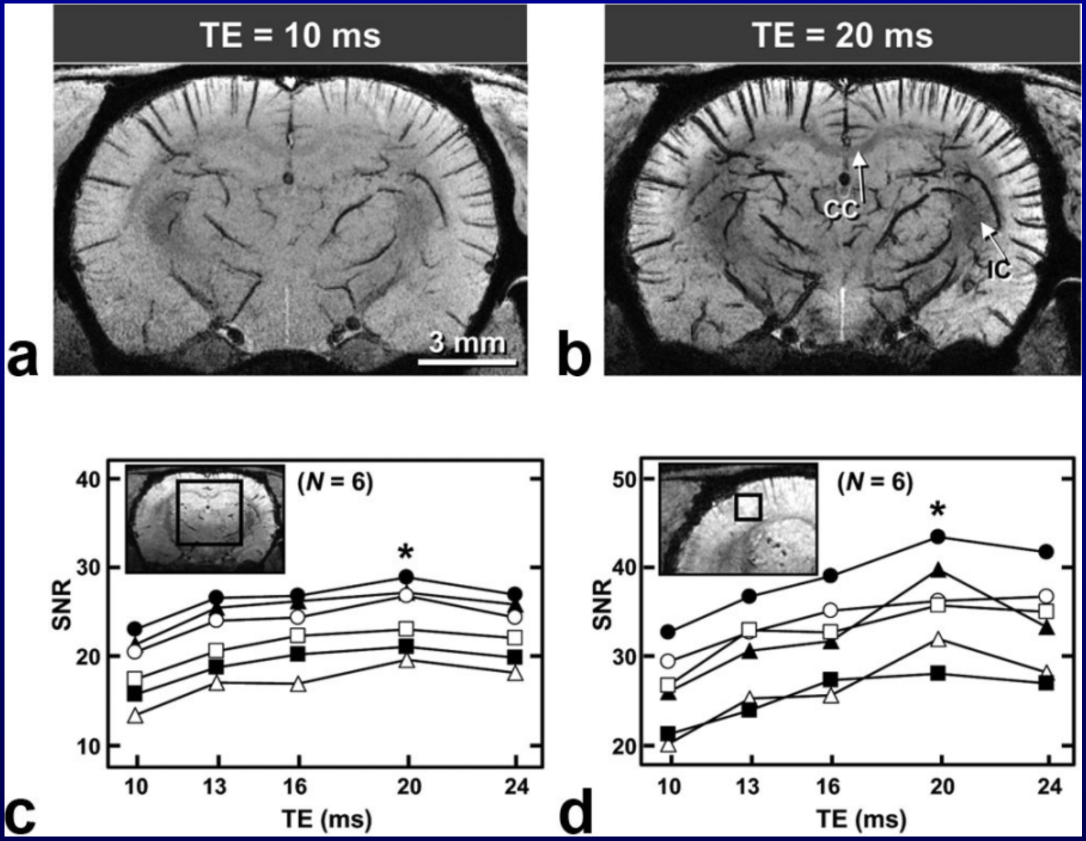
SWI (Phase-Mask Filtered)

Phase Images

Histology

Haacke et al,
Magn Reson Med
2004;52:612-618)

Susceptibility-Weighted Imaging at High Field



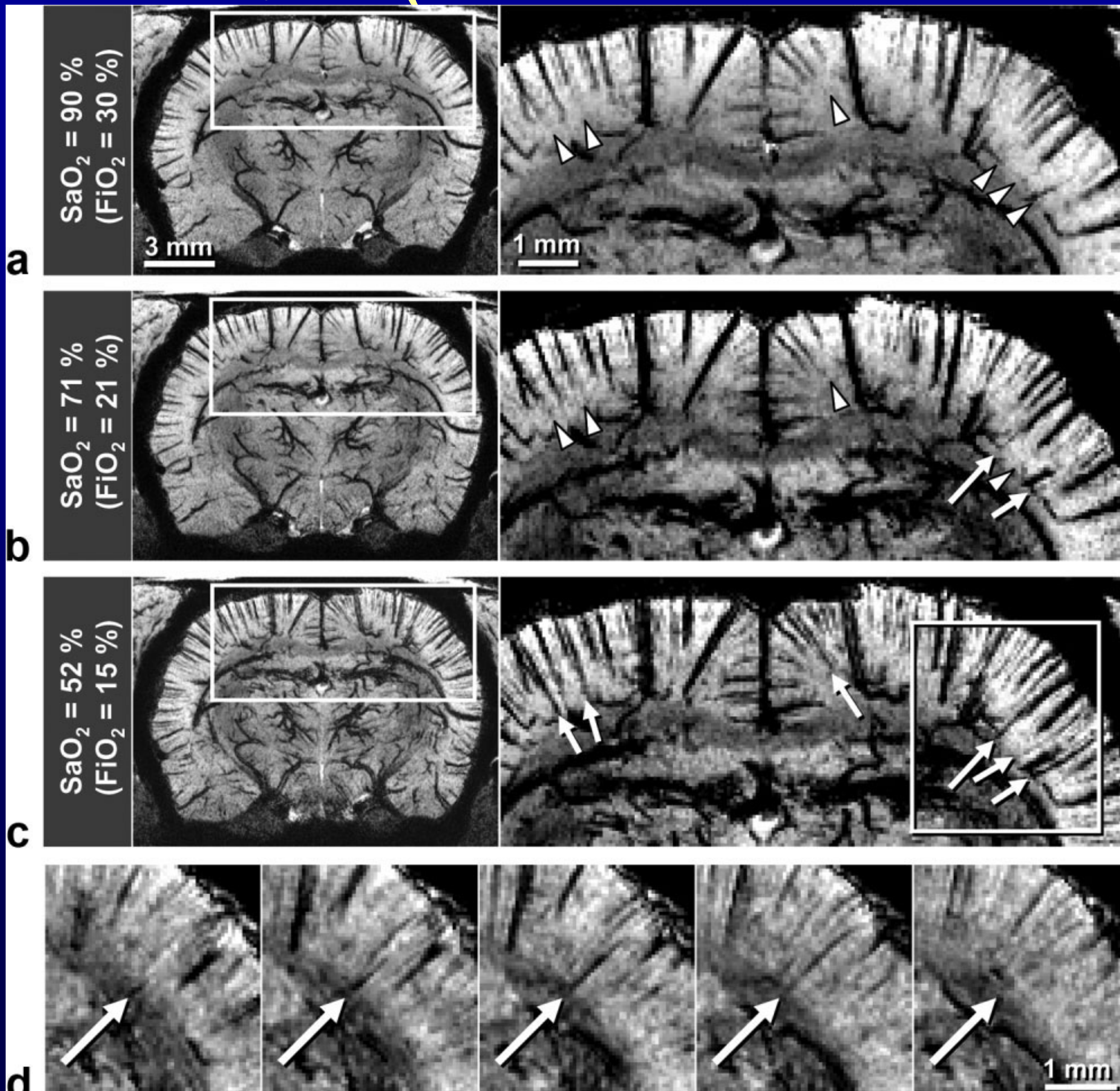
(Park et al, Magn Reson Med 2008;59:855-865)

- T_2 of venous blood : 190 ms at 1.5T, 100 ms at 3T, **7 ms at 9.4T**
- Low Field BOLD Venography (1.5T, 3.0T) : Set echo time for the phase difference between vein and other tissues to be 180° (25ms–50ms) and apply phase-mask filtering
- High Field BOLD Venography (9.4T)

→ Set echo time to be 3 or 4 times longer than T_2 of vein (20~25ms)

→ Natural T_2 or T_2^* decay suppresses venous signal. No specific post-processing.

Oxygenation-dependent BOLD Microscopy at 9.4T (No Phase-Mask Filtering)



(Park et al, Magn Reson Med 2008;59:855-865)

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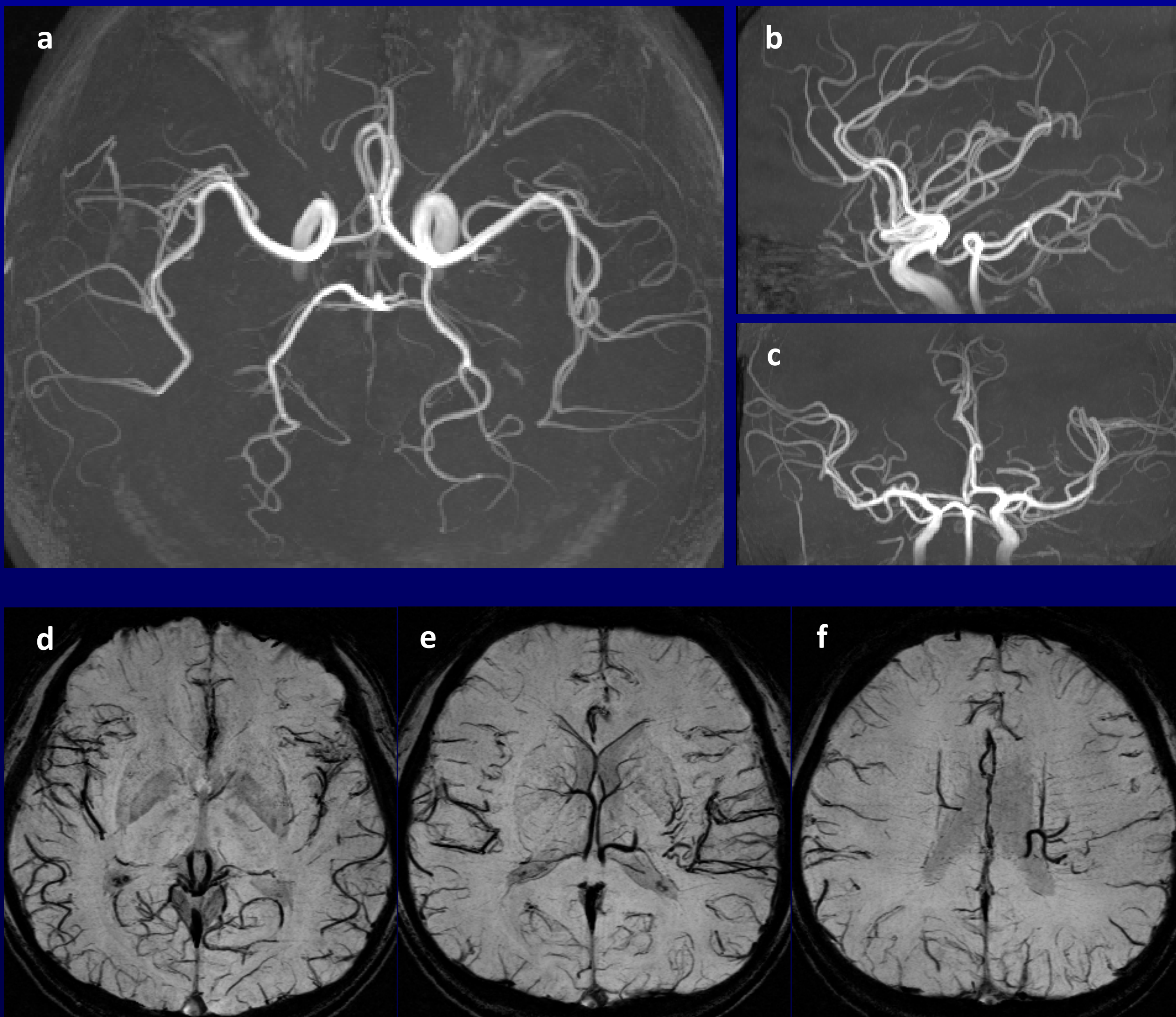
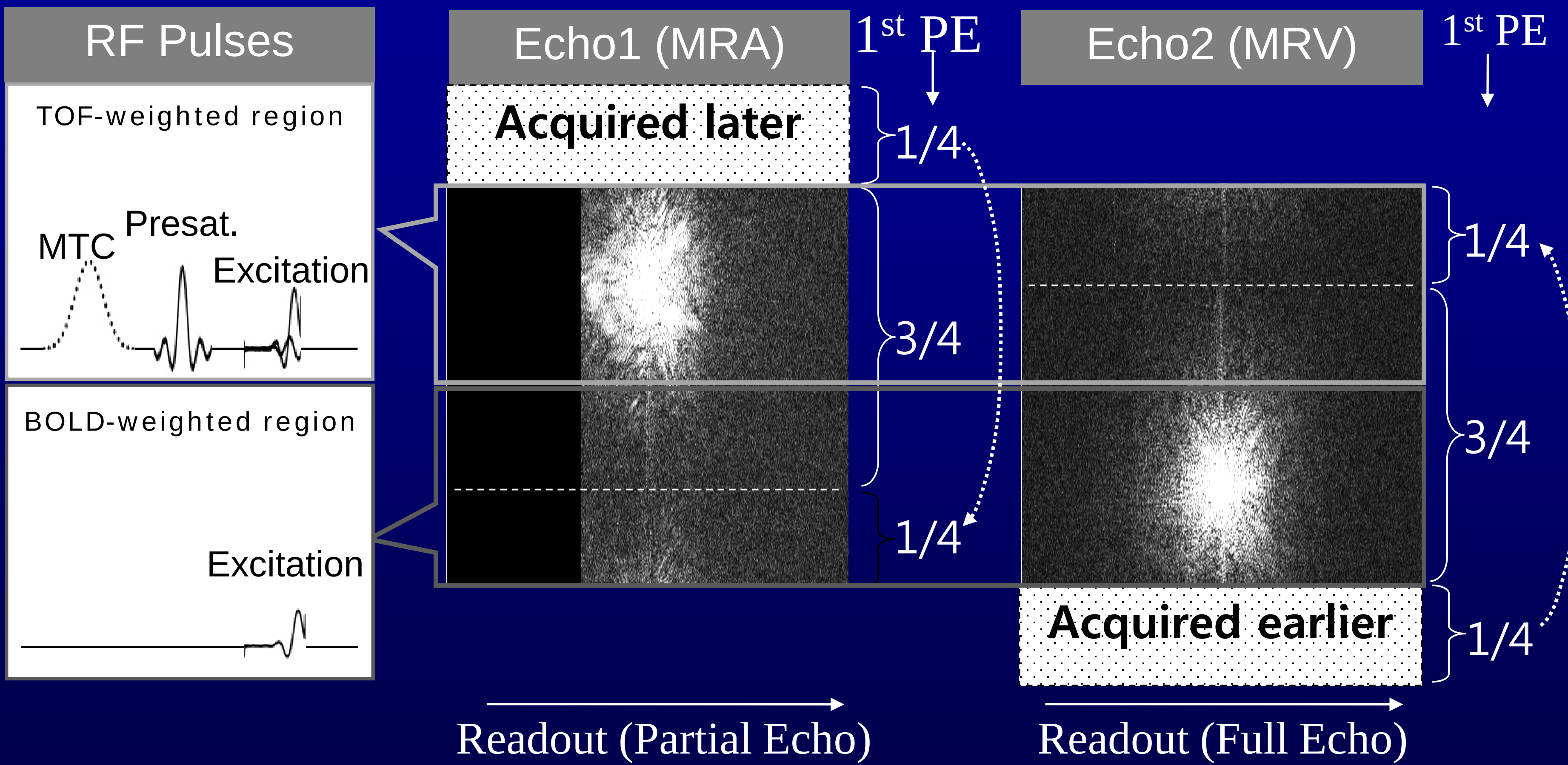
Compatible Dual-Echo Arteriovenography (CODEA)



Echo1(MRA)
/Echo2(MRV)

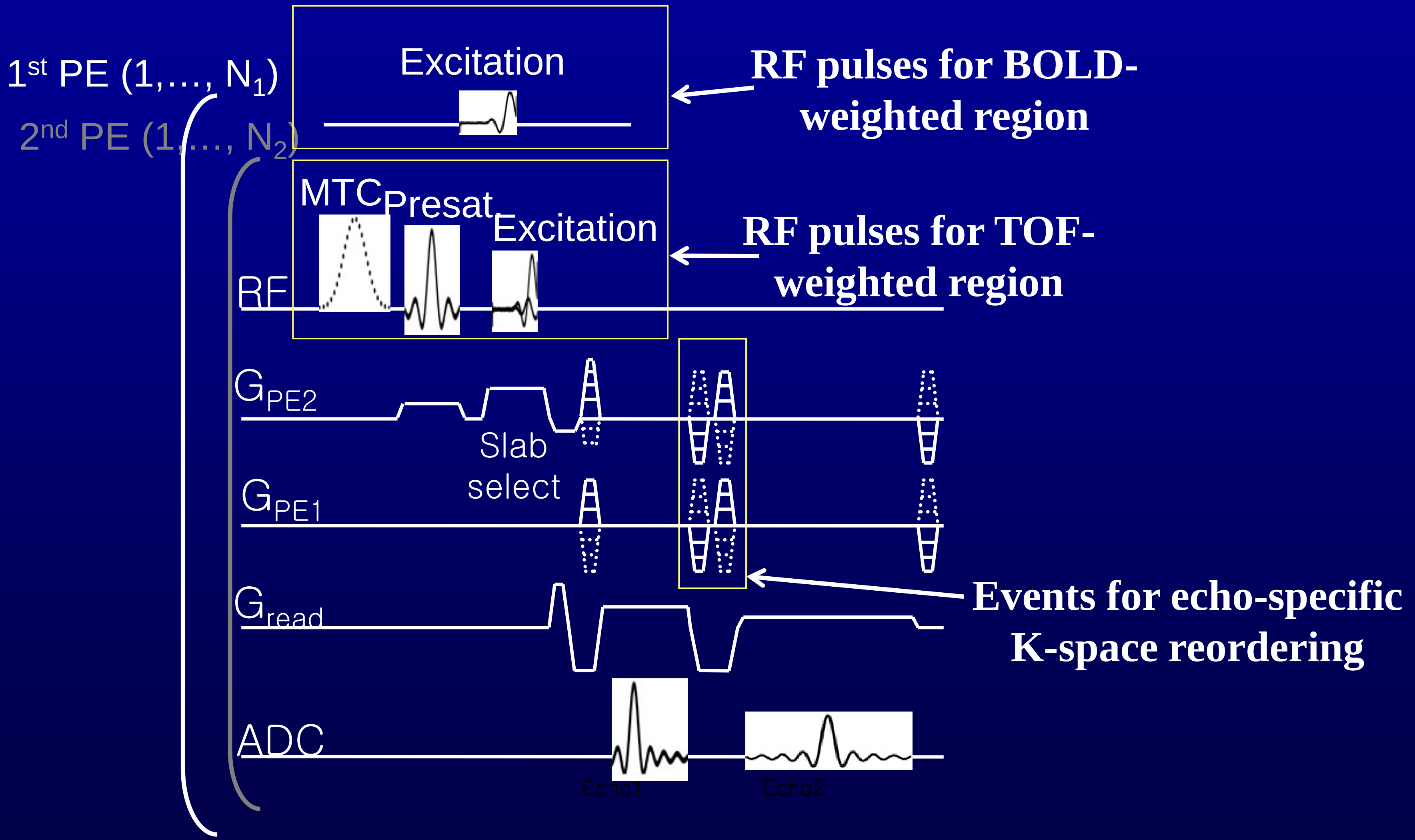
- TR: 40ms
- TE: **3.2/20ms**
- **Flip angle: 25°(ramp) / 15°(flat)**
- **Presaturation: on/off**
- FOV: 240x180x80mm^3
- Mat : 512x192x64
- ST : 9.8 min
- **Echo-specific K-space reordering scheme**

K-space Reordering in CODEA



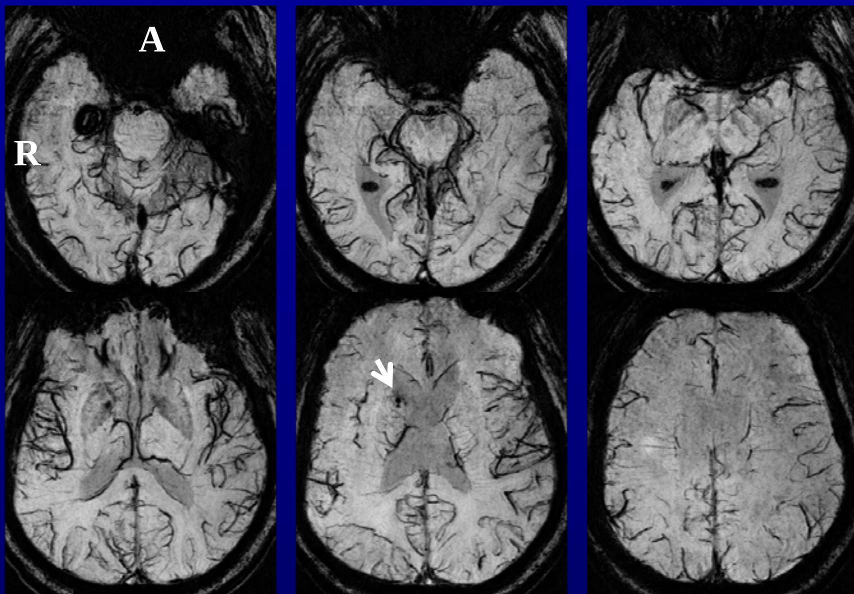
Park et al, Magn Reson Med 2009; 61(4):767-774

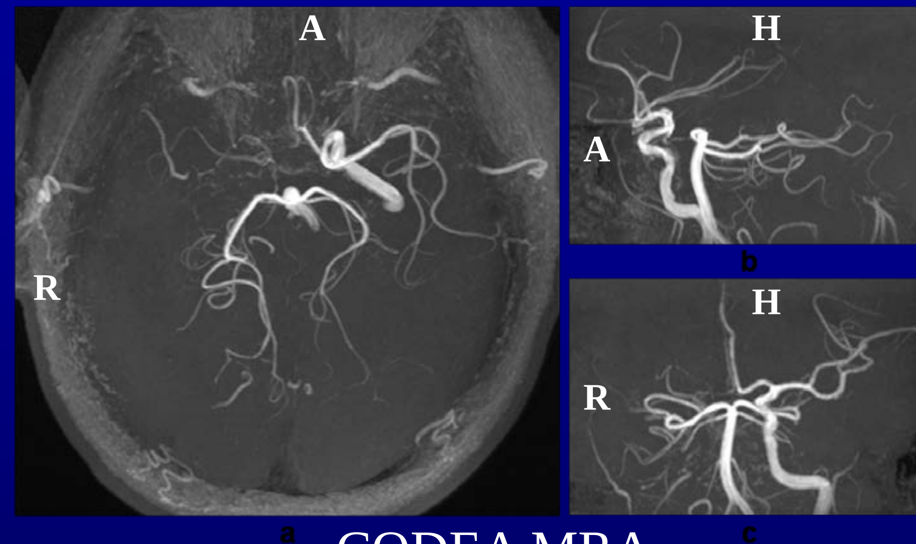
Pulse Sequence Diagram for CODEA



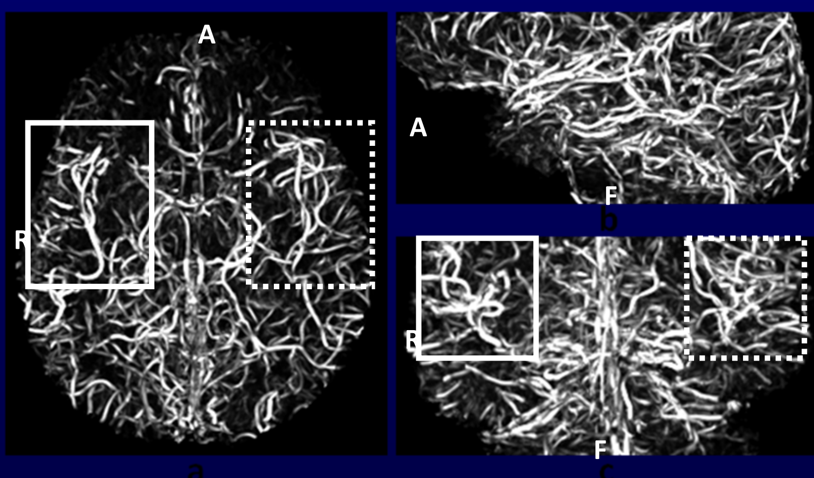
Park et al, Magn Reson Med 2009; 61(4):767-774

CODEA in Chronic Stroke Patients





CODEA MRA



CODEA MRV

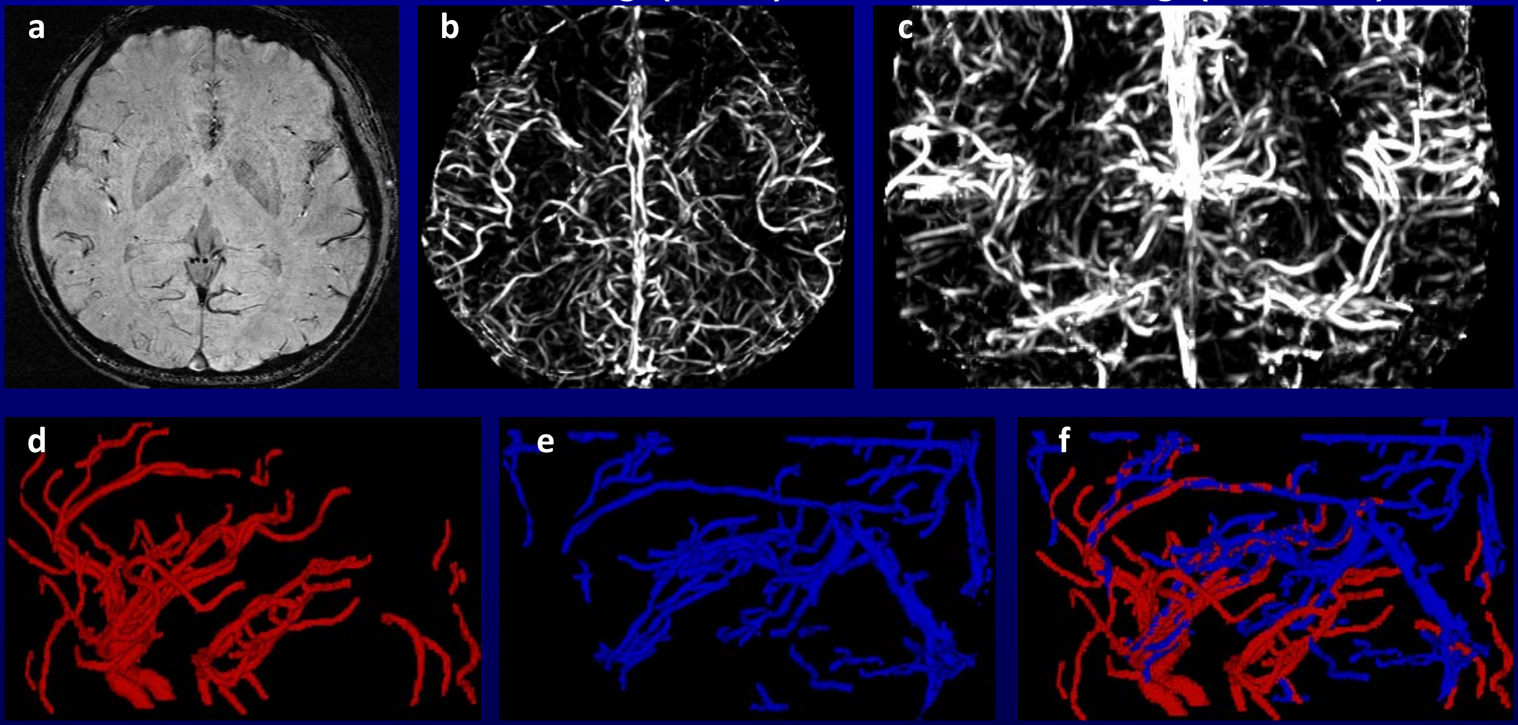
- CODEA MRA detected arterial occlusion.
- CODEA MRV detected reduced venous vascularity and some hypointense structures in regions of arterial occlusion.

Segmentation of Arteries & Veins

CODEA MRV

CODEA MRV Vessel-Enhancement Filtering (Axial)

CODEA MRV Vessel-Enhancement Filtering (Coronal)



CODEA MRA (volume rendering)

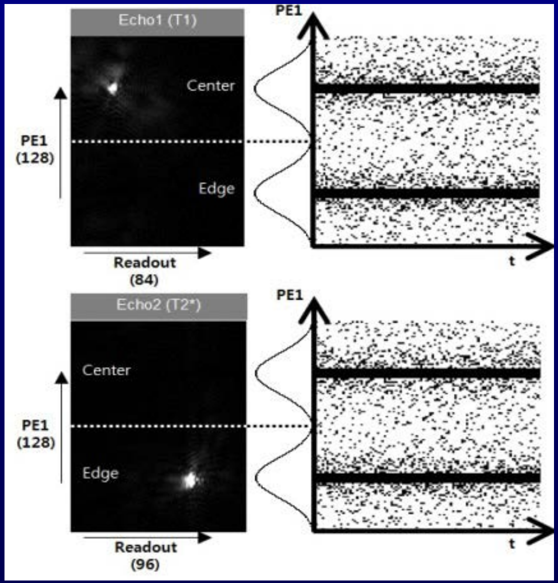
CODEA MRV (volume rendering)

CODEA MRA/MRV (volume rendering)

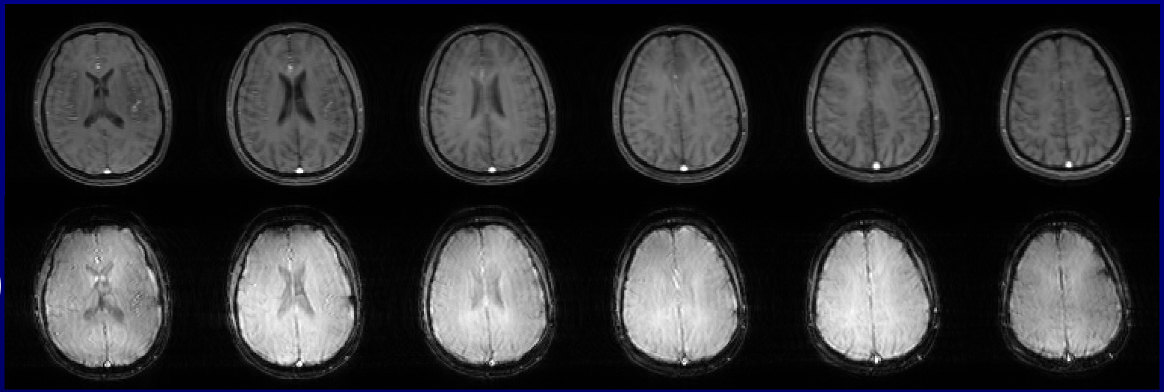
Shim H, Park SH, and Bae KT, Proc. Int. Soc. Magn. Reson. Med, 2009, p654

Dynamic T_1 and T_2*-w Imaging (Simultaneous *DCE*-*DSC* Imaging)

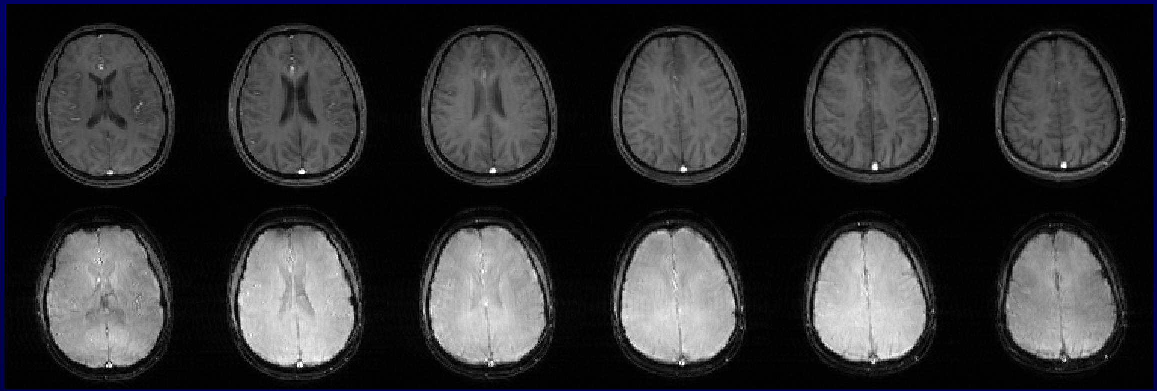
도원준



Full (16s)



CS4 (5s)



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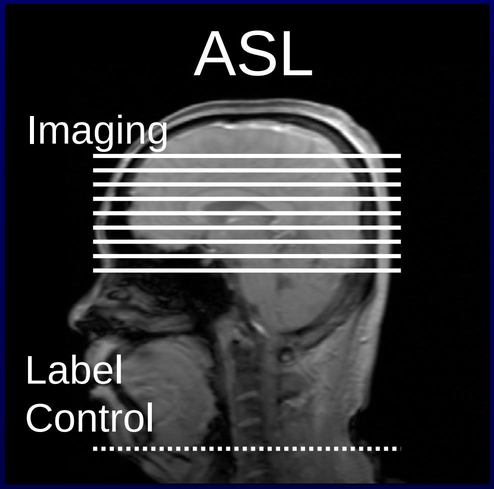
Arterial Spin Labeling (ASL)

- MR Perfusion-Weighted Imaging
  - With contrast agent
  - Arterial Spin Labeling without contrast agent
- Acquisition of one image with arterial bloods inverted (labeled) prior to the acquisition.
- Acquisition of another image with no labeling of arterial bloods (control)
- Subtraction between the two images → ASL
- Pulsed ASL (PASL)
  → Adiabatic inversion RF pulse
- Continuous ASL (CASL)
  → Constant long RF and gradient pulses
  → Flow-driven adiabatic inversion
- Pseudo-continuous ASL (pCASL)
  → CASL with multiple short RF pulses



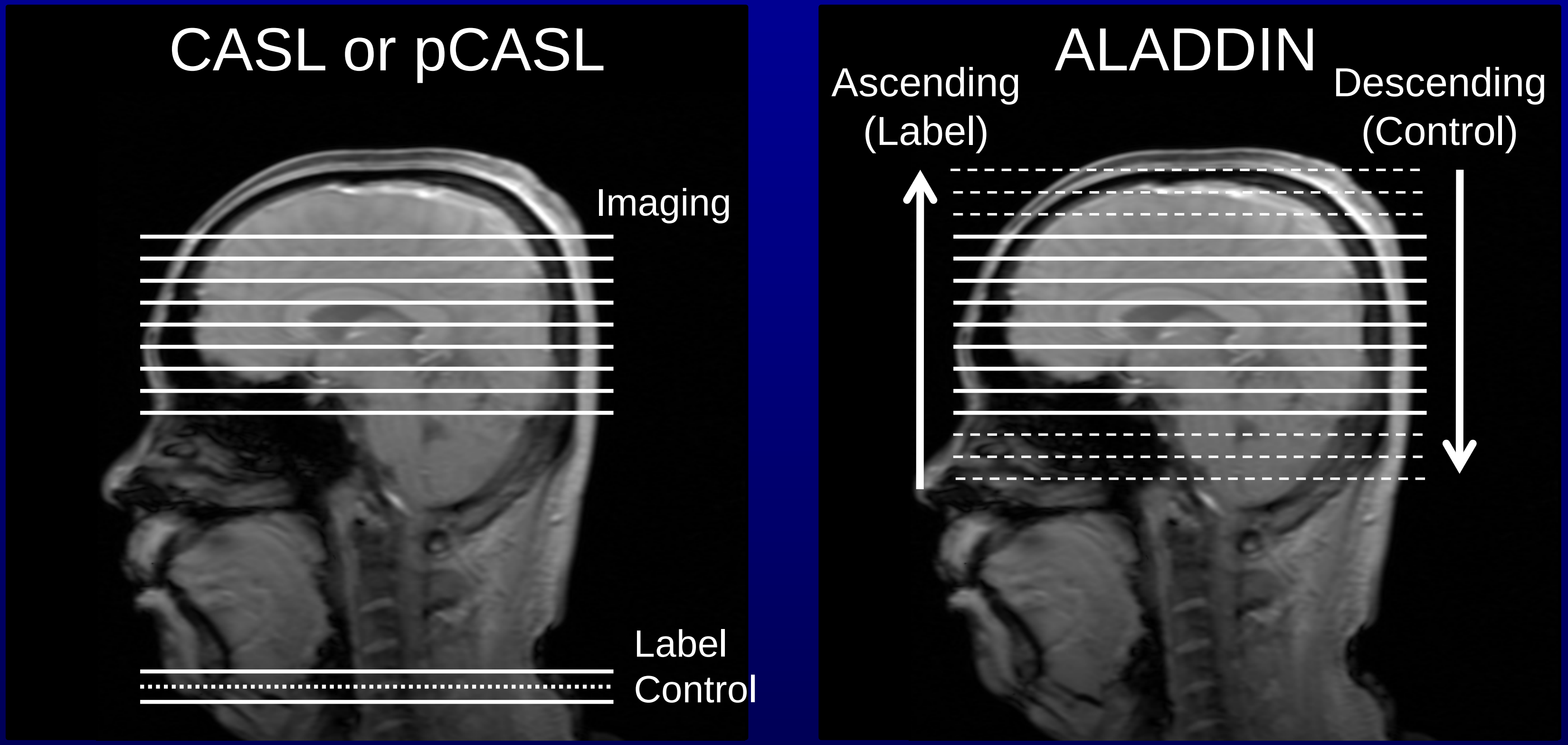
Alternate Ascending/Descending Directional Navigation (ALADDIN)

- All ASL techniques require spin preparation.
  - Pulsed ASL (PASL)
  - Continuous ASL (CASL)
  - Pseudo-continuous ASL (pCASL)

- Limitations
  - Low percent signal changes
  - Narrow time window for perfusion contrast
  - Sensitivity to tissues with heterogeneous arterial transit time
  - No perfusion directionality

→ New approach (ALADDIN)

Schematic Diagram for ALADDIN

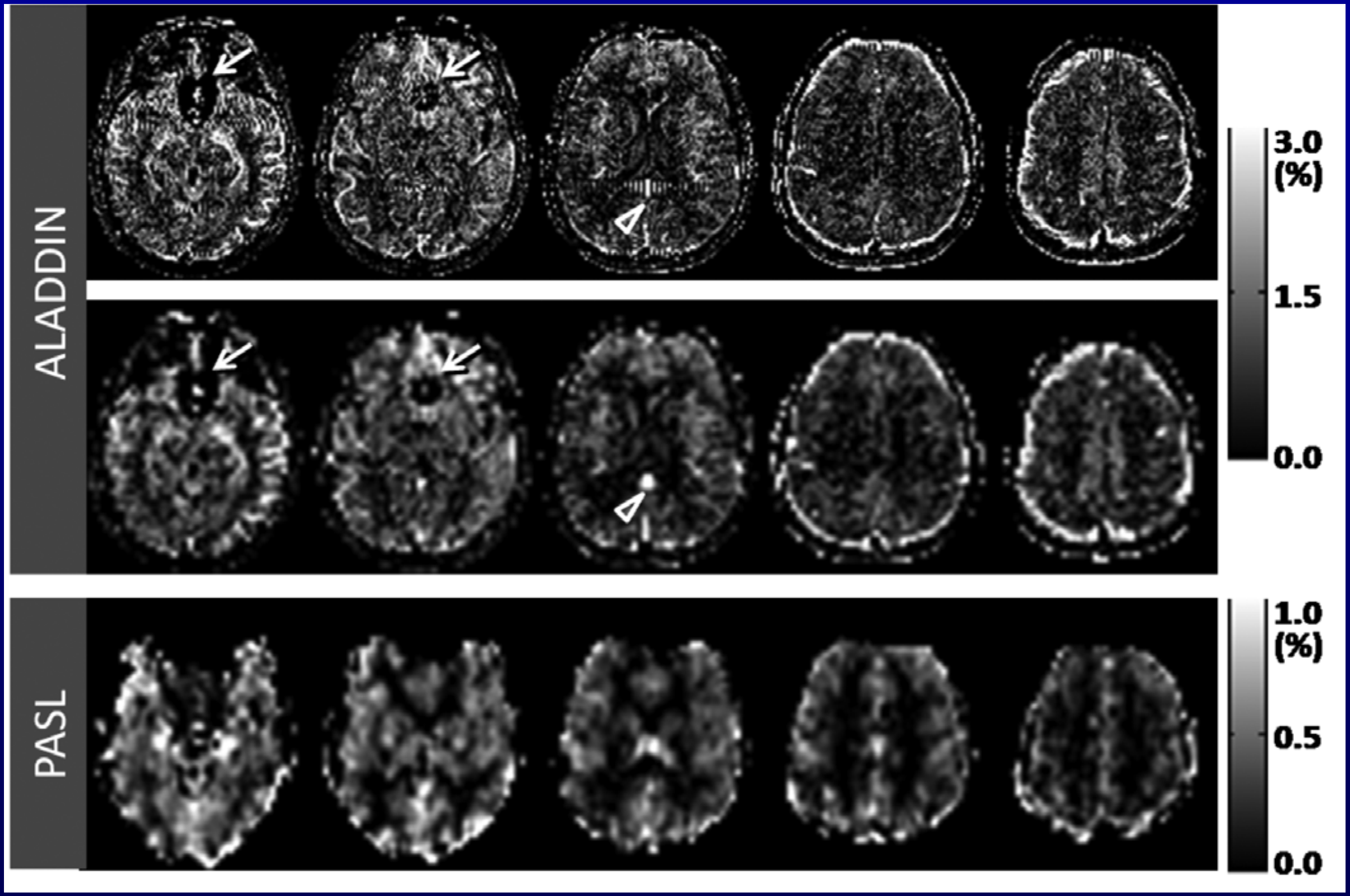


ALADDIN : Alternate Ascending/Descending Directional Navigation

Park and Duong, Magn Reson Med 2011; 65(6):1578-1591

ALADDIN ASL

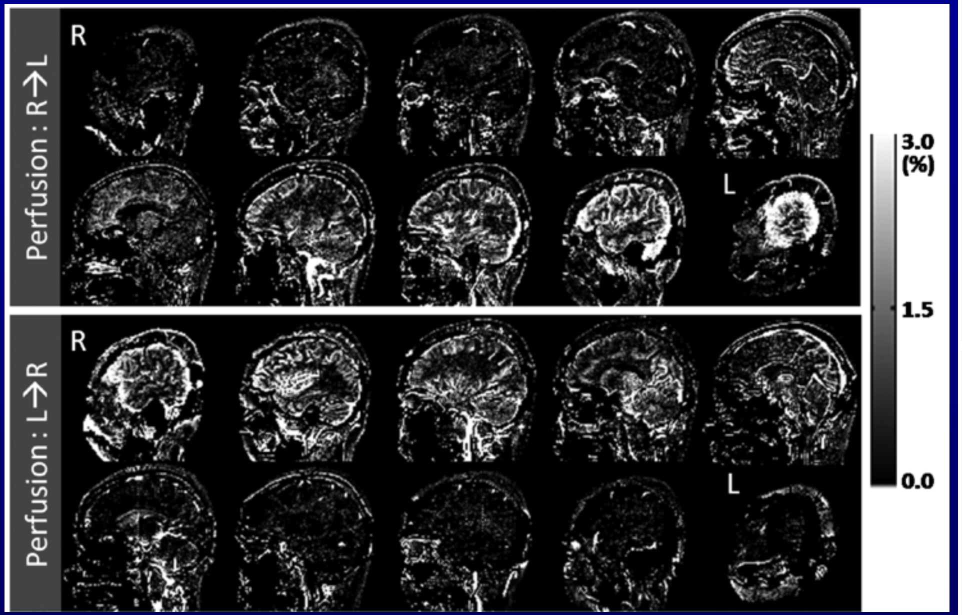
PASL vs ALADDIN

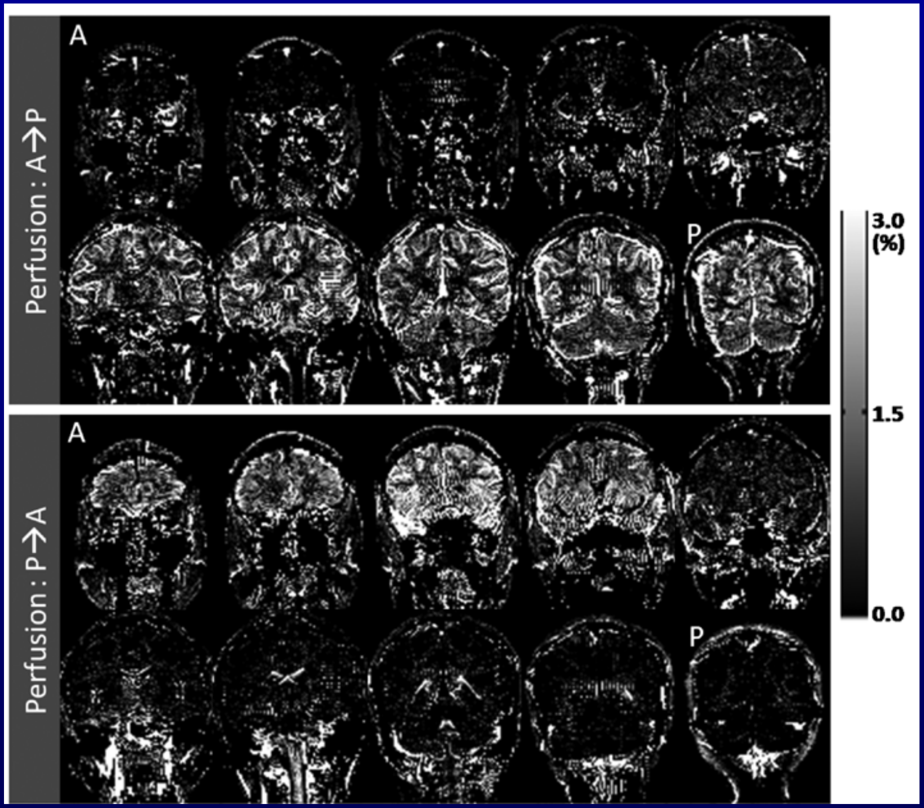


Park and Duong, Magn Reson Med 2011; 65(6):1578-1591

- Higher percent signal changes in ALADDIN.
- No susceptibility artifacts but signal voids in the regions of banding artifacts (arrows) in ALADDIN.
- Flow artifacts in ALADDIN (arrowheads)

Sagittal & Coronal Images

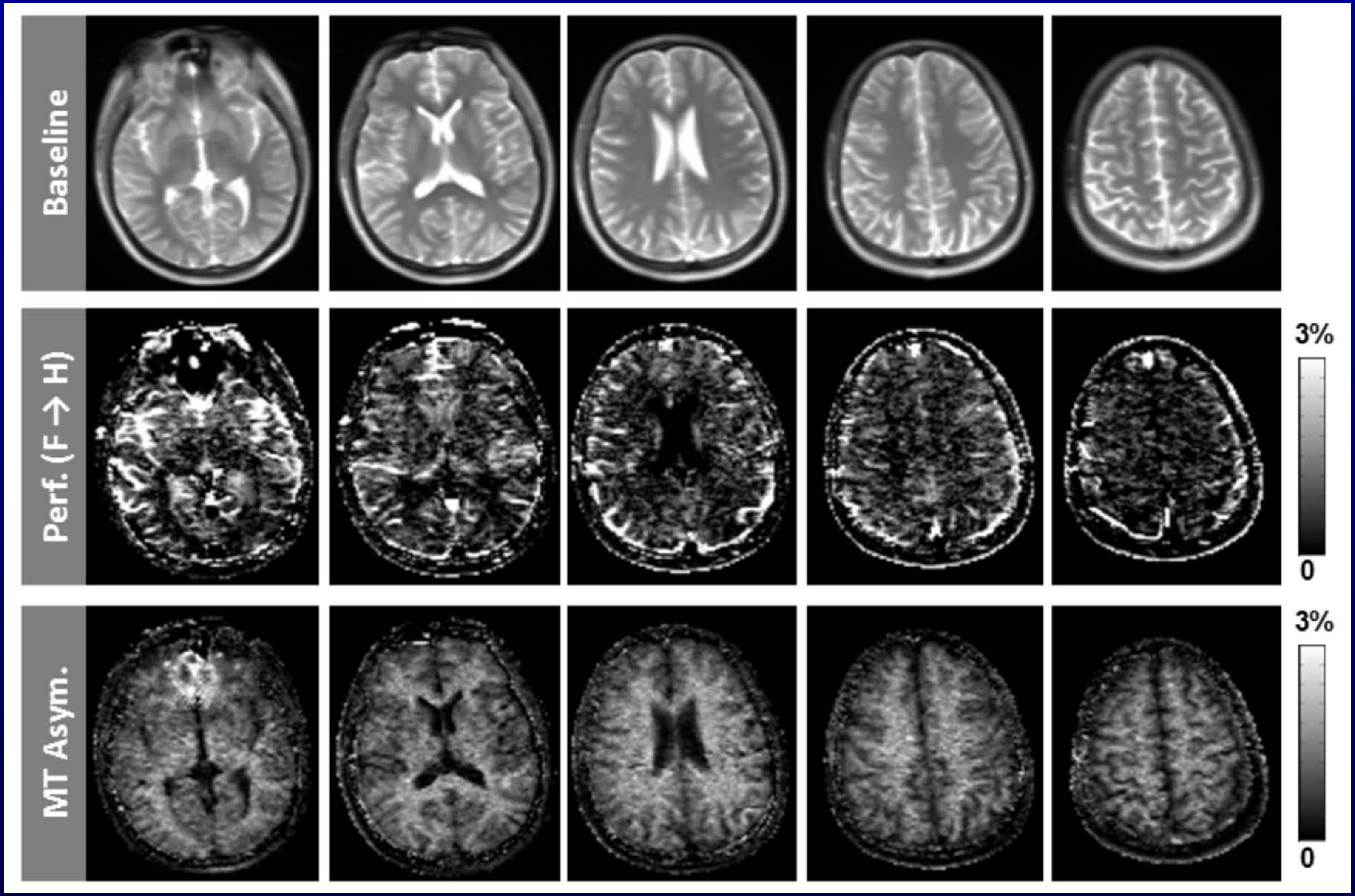




- Changes in perfusion direction between hemispheres
- Most GM perfusion was from medial to lateral.
- Perfusion direction in some WM was opposite to that of GM.

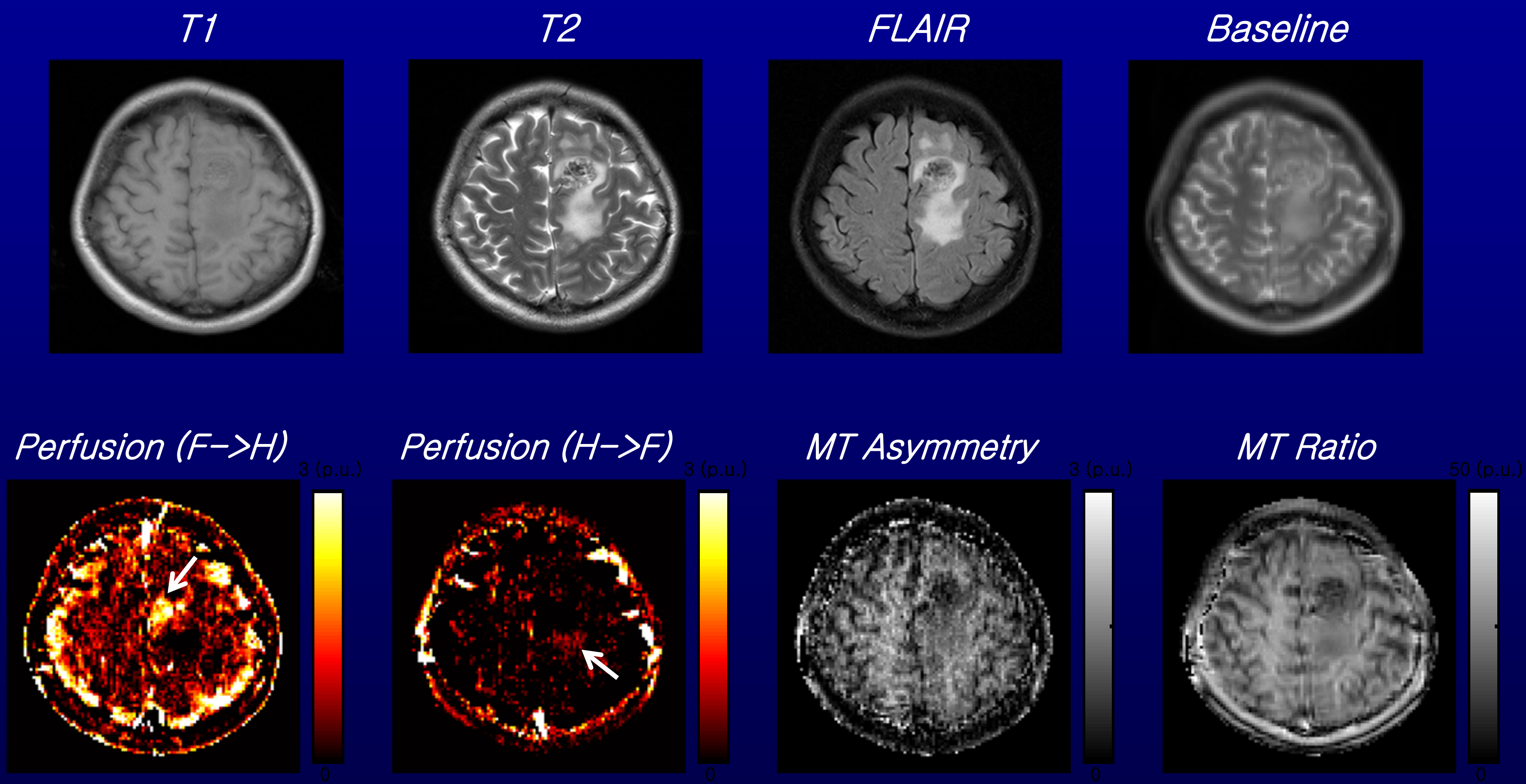
Park and Duong, Magn Reson Med 2011; 65(6):1578-1591

Simultaneous CBF and MT Asymmetry Imaging with ALADDIN

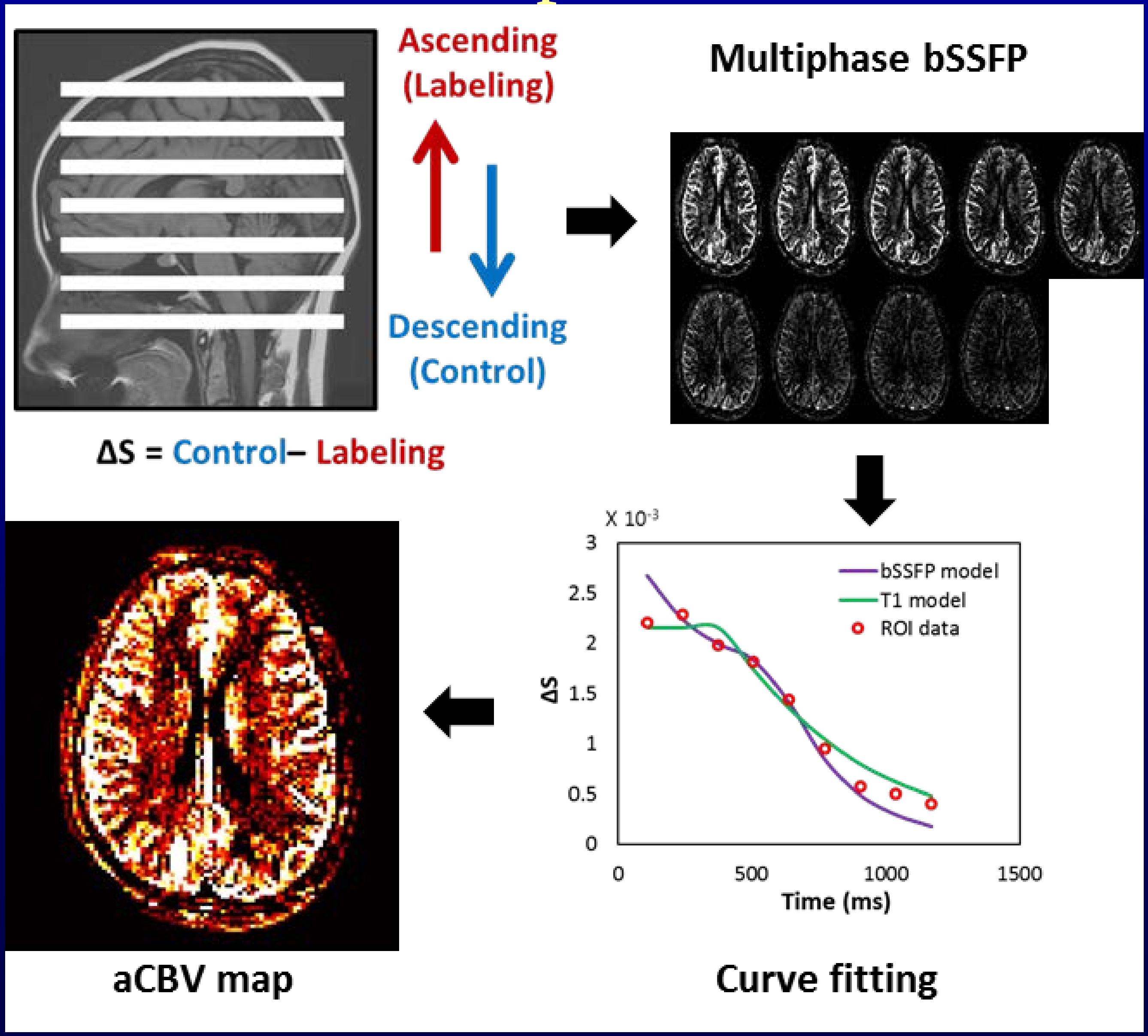


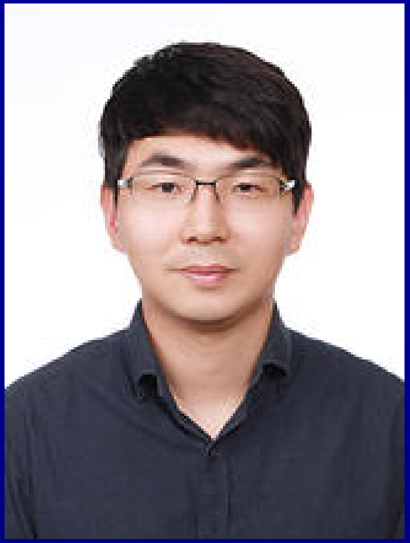
ST = 3 min

Simultaneous CBF, MTR_{Asym}, and MTR Imaging with ALADDIN for Meningioma



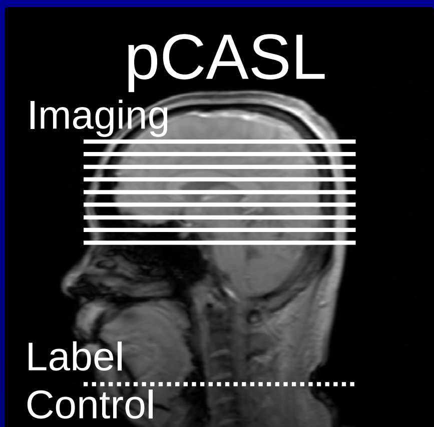
Multiphase ALADDIN

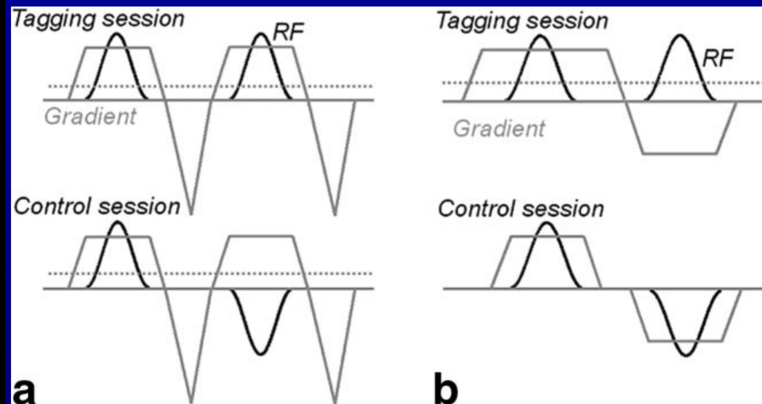




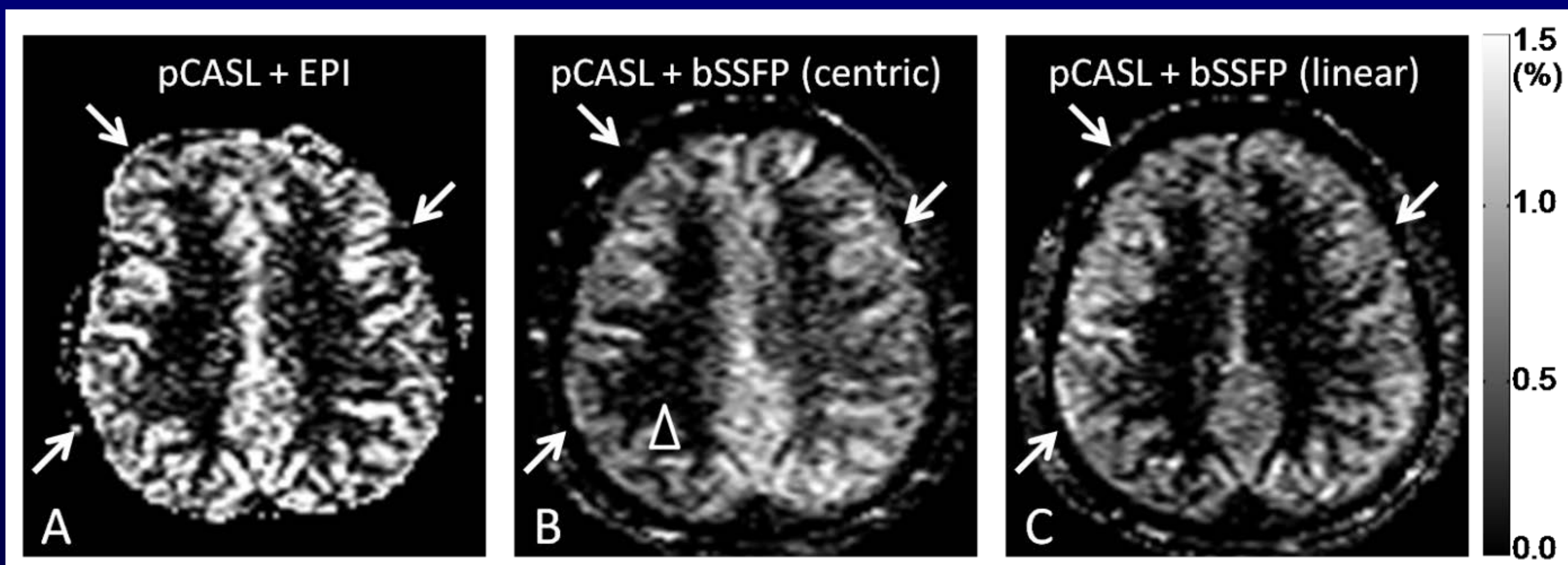
김기환

Pseudo-Continuous ASL with bSSFP Readout (1) Brain



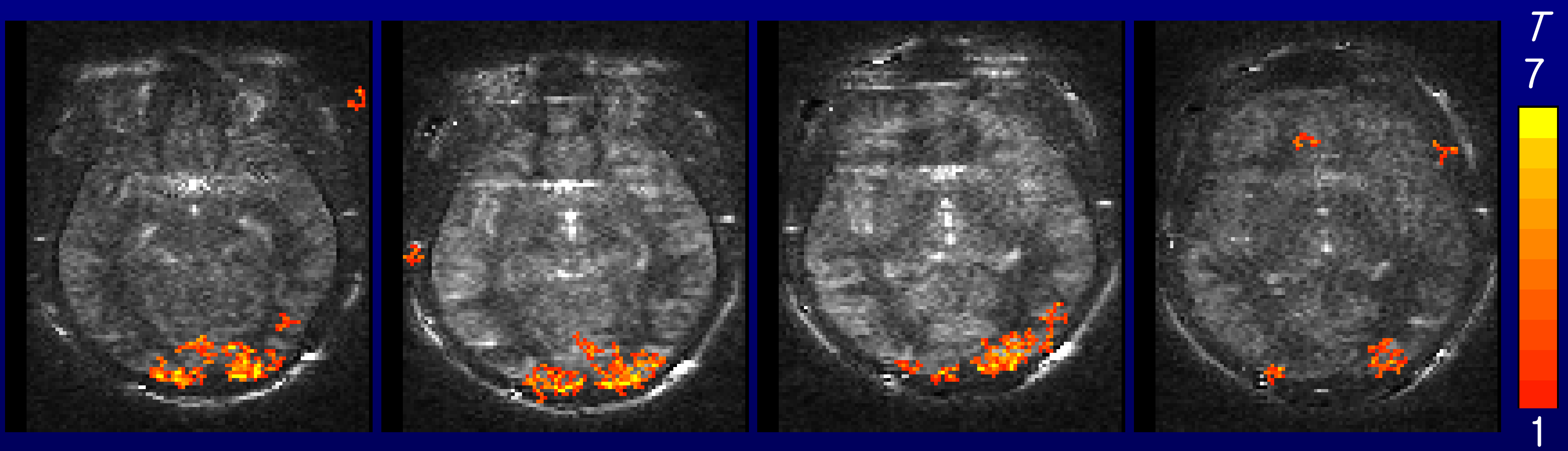


Wu et al, MRM 2007;58:1020–1027
Dai et al, MRM 2008;60:1488–1497



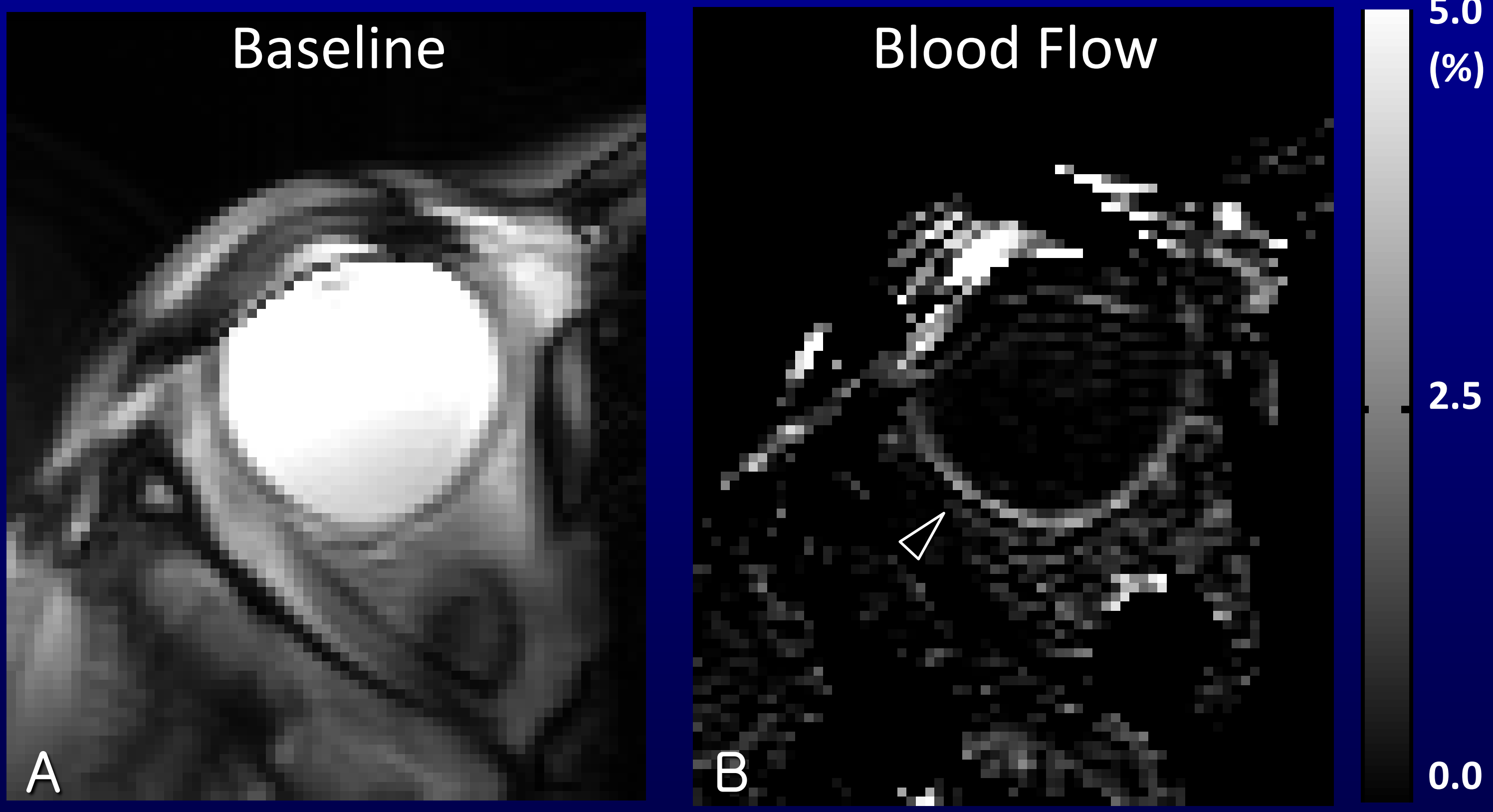
Park et al, Magn Reson Imag 2013;31(7):1044-1050

Pseudo-Continuous ASL with bSSFP Readout (2) fMRI



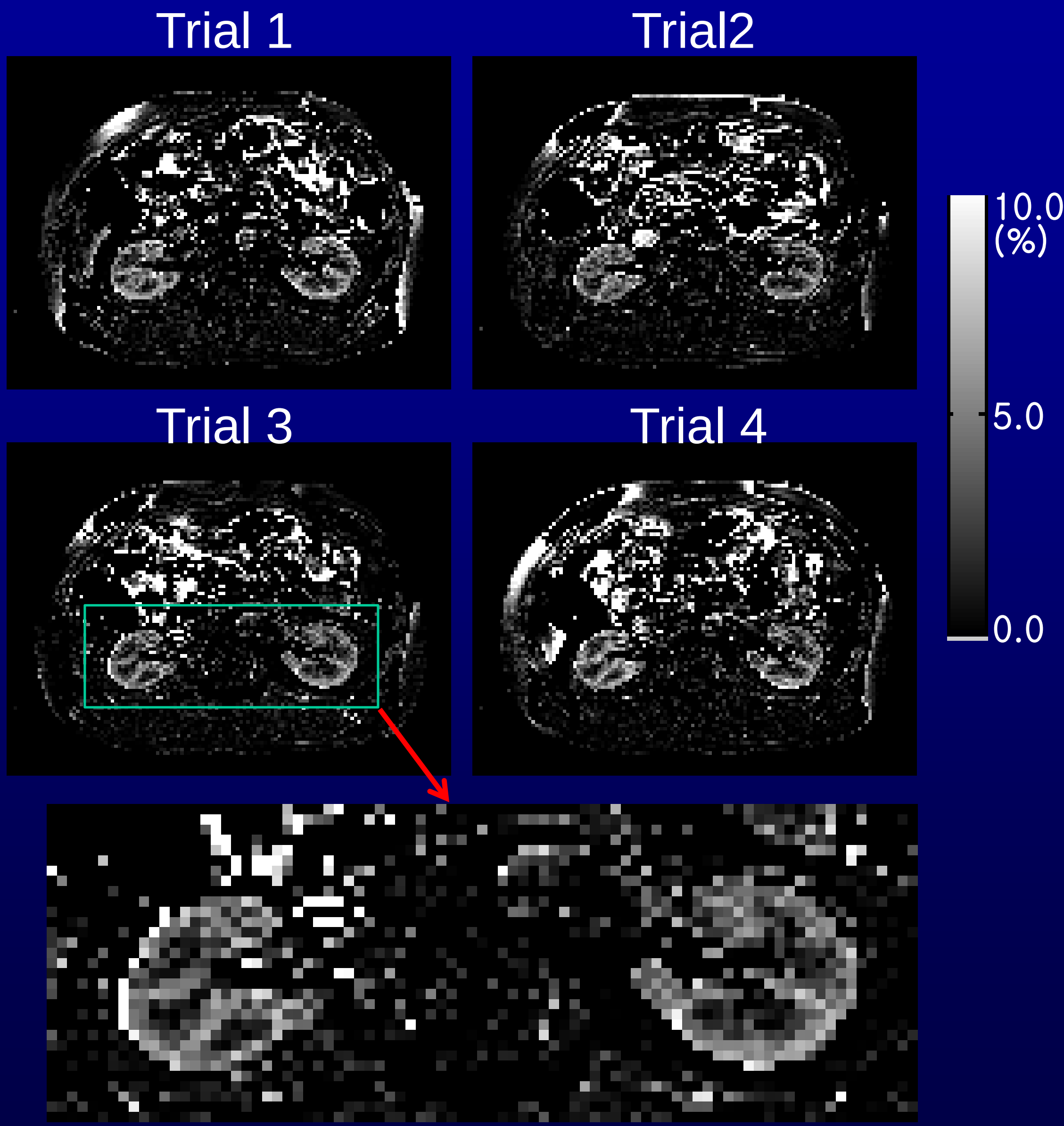
Park et al, Magn Reson Imag 2013;31(7):1044-1050

pCASL-bSSFP for Human Retina



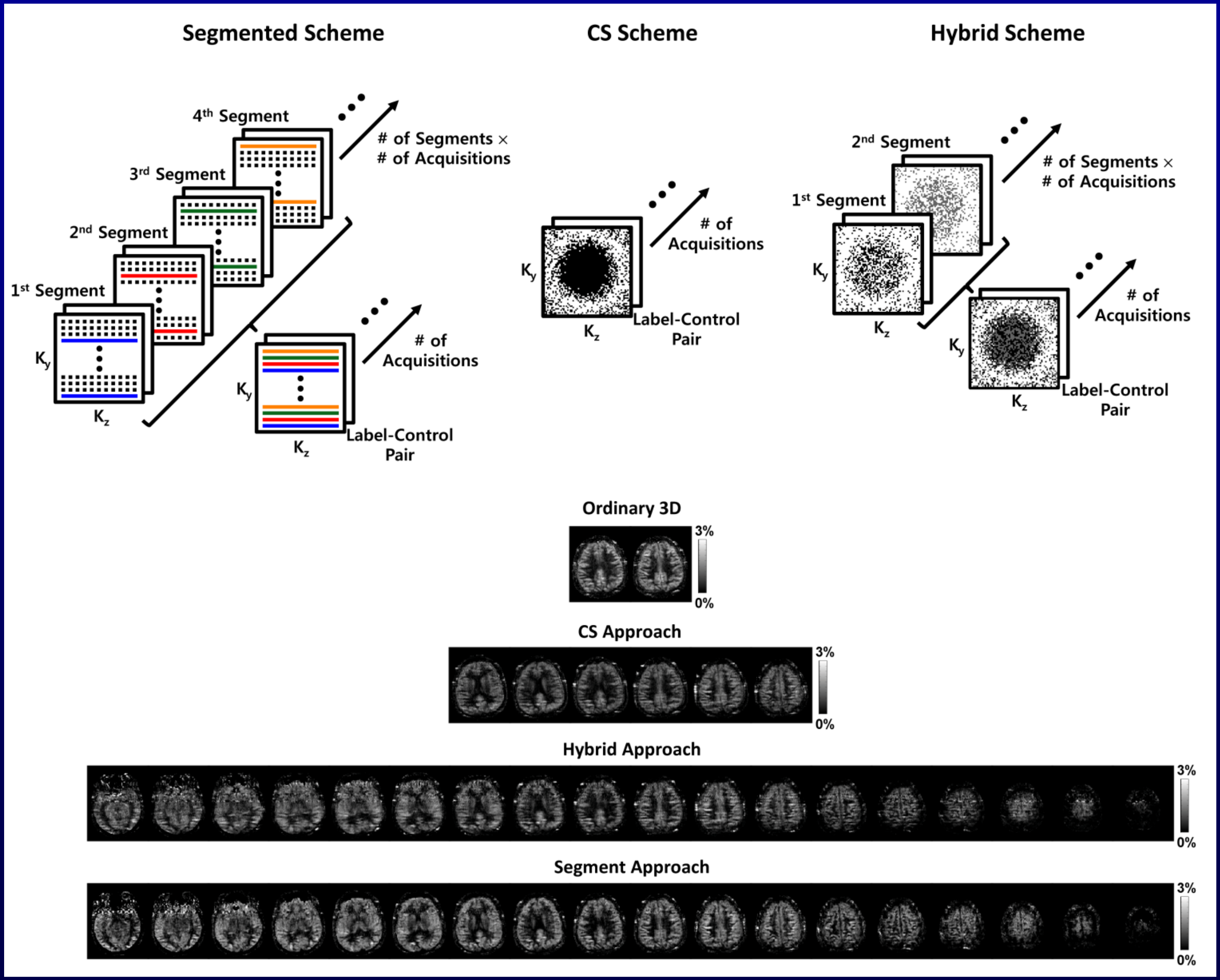
Park et al, Magn Reson Imag 2013;31(7):1044-1050

pCASL-bSSFP for Human Kidney



- The pCASL-bSSFP for kidney within **single breath hold** was reproducible.
- The percent signal change in renal cortex was ~4 times higher than brain cortex.

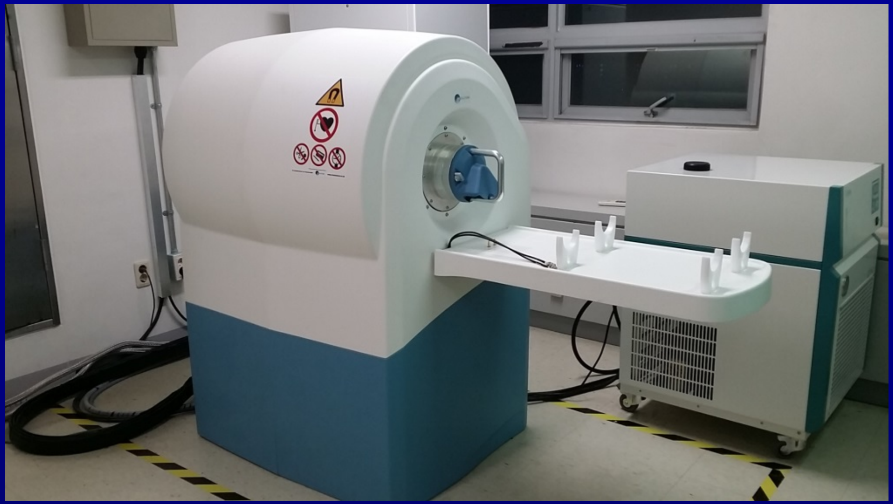
pCASL-bSSFP in the Whole Brain



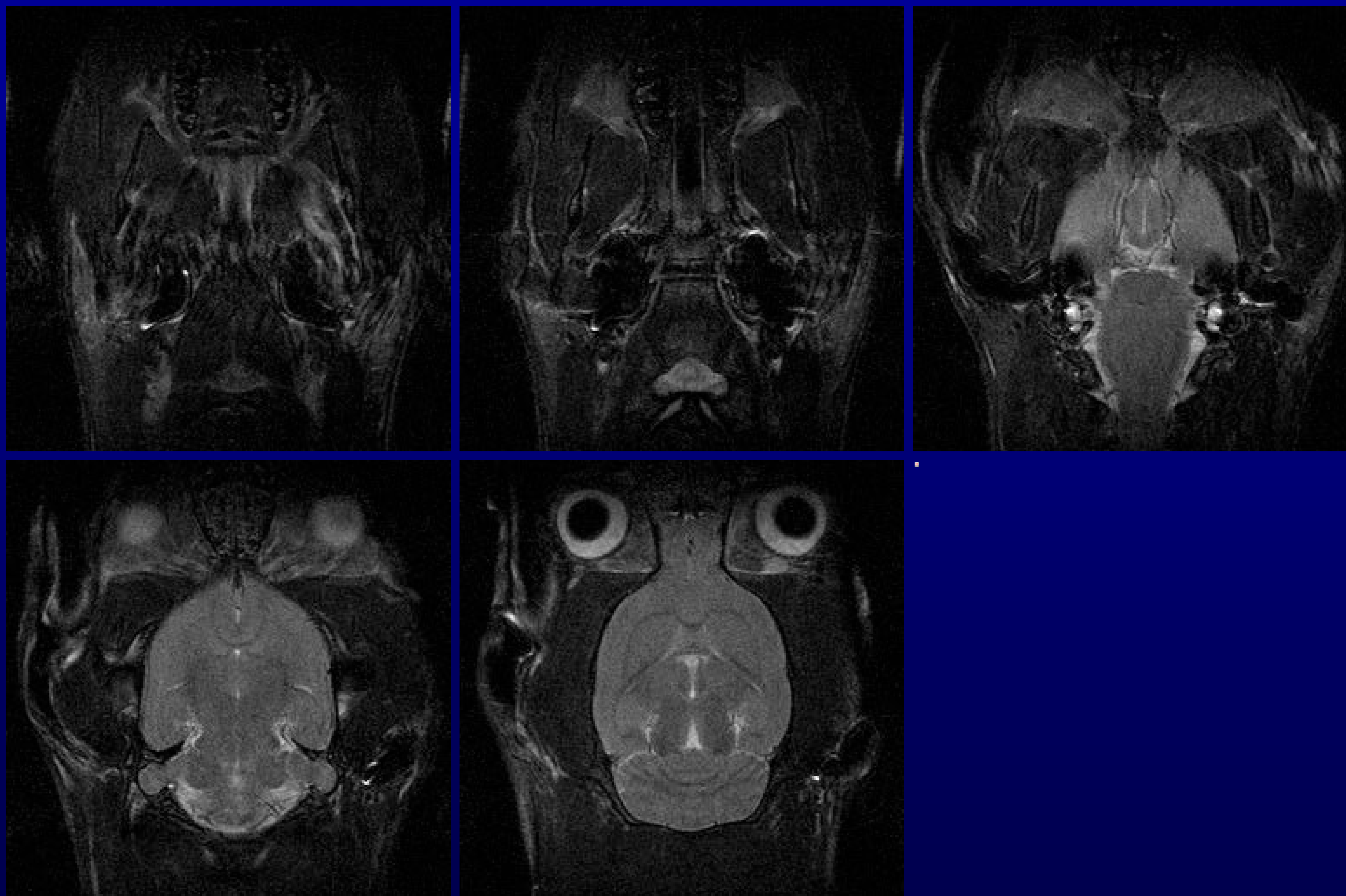
한폴규

New Helium-Free Superconducting 3T Animal MRI Scanner

MRI Pictures



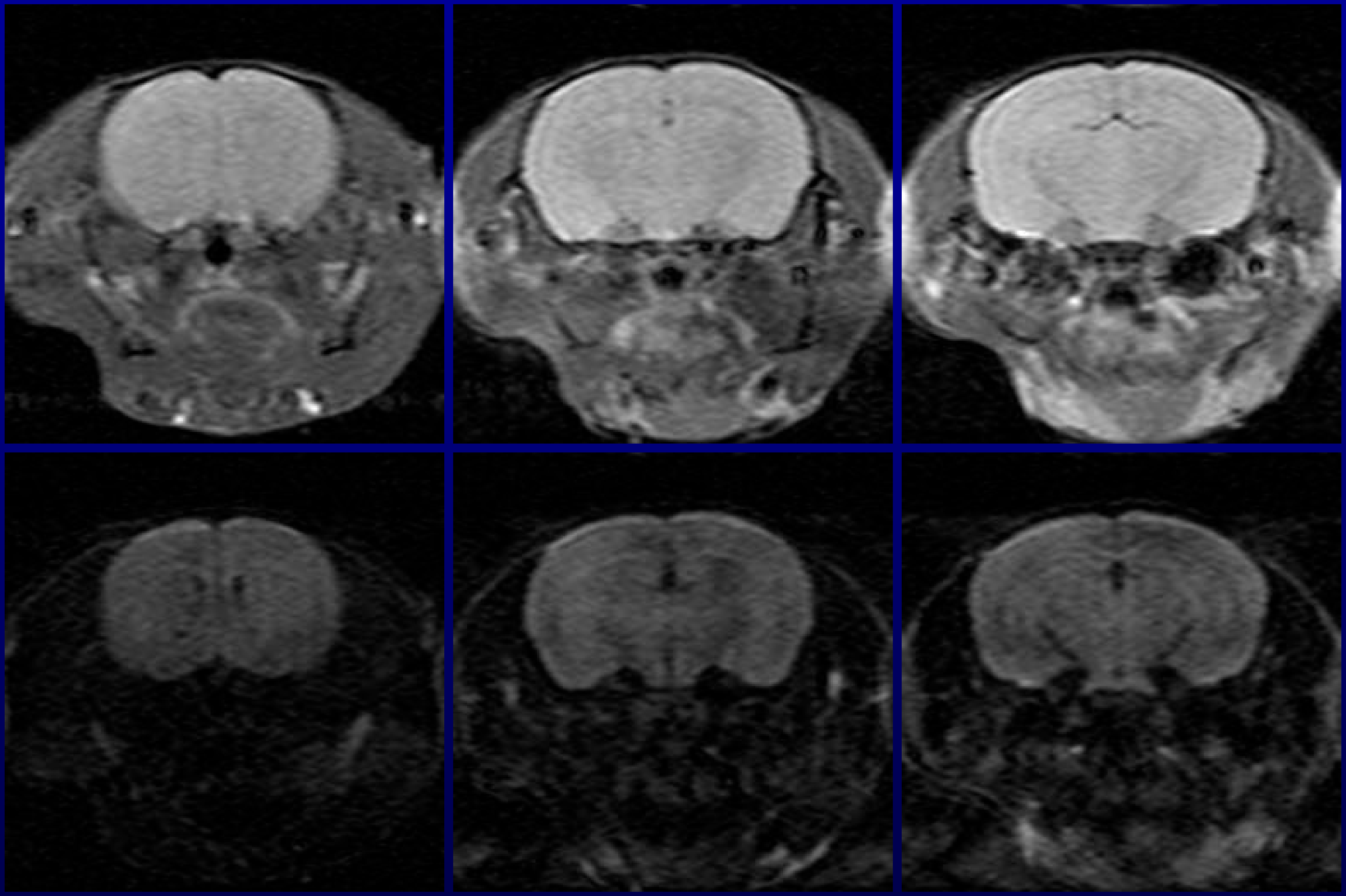
MRI Images (1) Rat T2-w Images



(2) Mouse T2-w Images

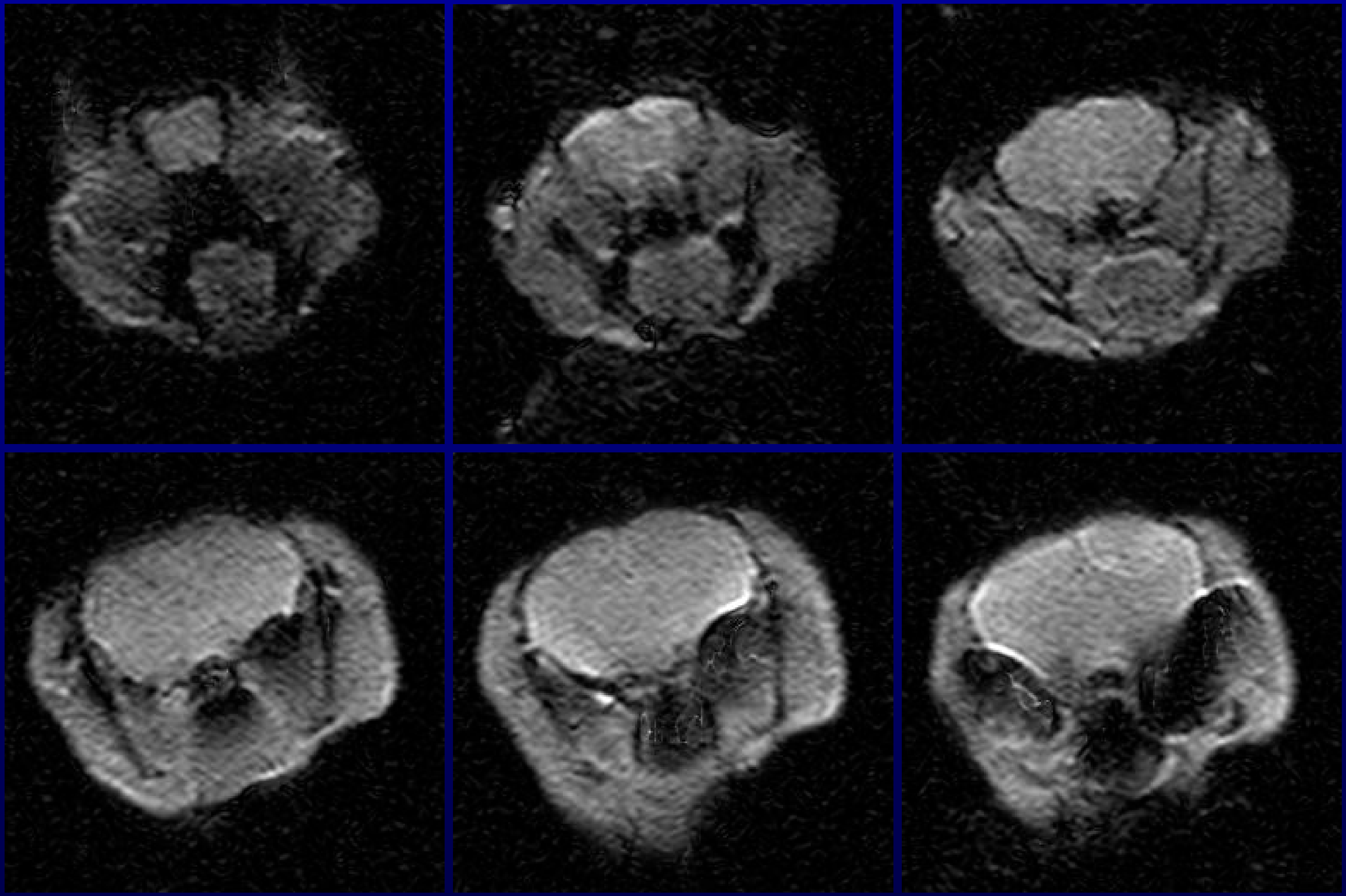
# of slice : 18, NA : 4, TR : 4800 ms, TE : 68 ms, Thickness : 1 mm, FOV : 15 X 15 mm^2, Matrix size : 256 X 256, Scan time : 10m 13s

(3) Mouse Diffusion-weighted Images



# of slice : 6, NA : 1, TR : 2000 ms, TE : 30 ms, Thickness : 1 mm,
FOV : 15 X 15 mm^2, Matrix size : 128 X 64, b=1000, Scan time : 4m 32s

(4) Mouse Echo Planar Images



# of slice : 12, NA : 1, TR : 2000 ms, TE : 10 ms, Thickness : 1 mm, FOV : 20 X 20 mm^2, Matrix size : 96 X 68, Scan time : 27s

Acknowledgement

- KAIST

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Dr. Hackjoon Shim
Dr. Chan-Hong Moon

Dr. Edwin Nemoto

- Research Imaging Institute / UTHSCSA

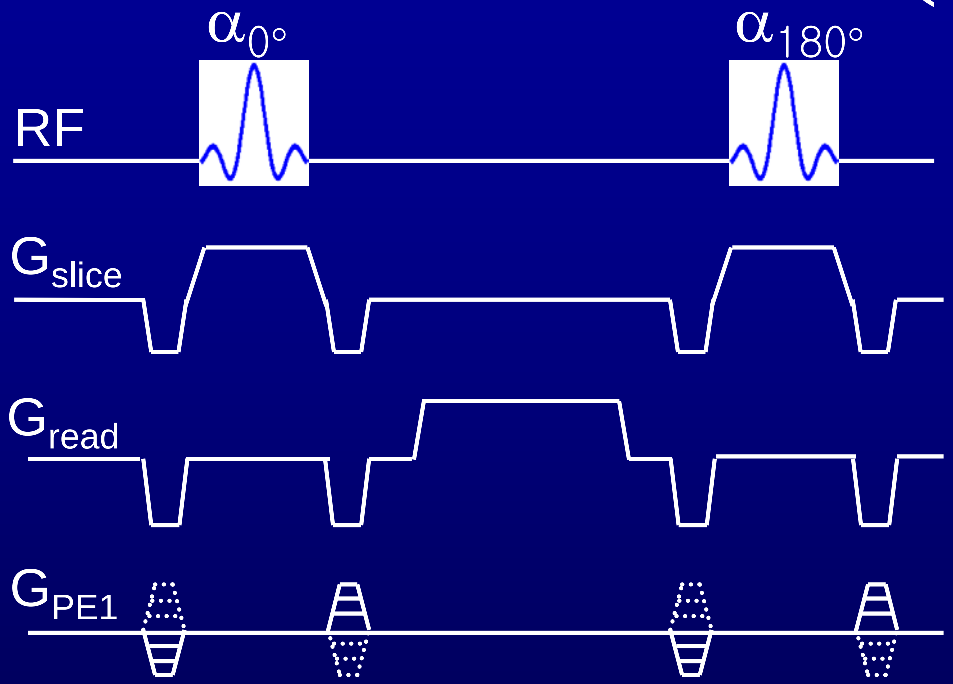
Dr. Peter T Fox
Dr. Timothy Q Duong

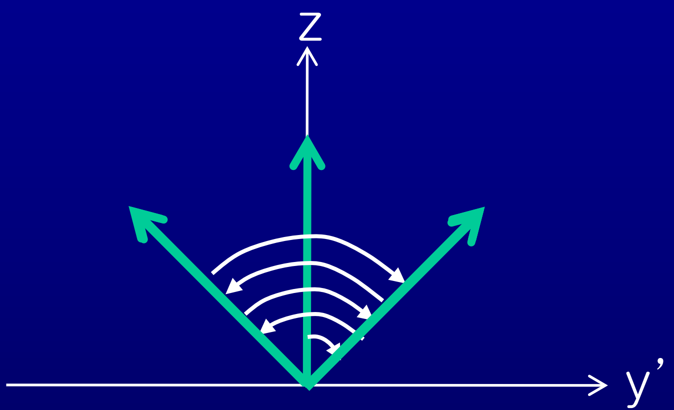
- Univ. California LA

Dr. Danny J. Wang

Thank you.

Balanced Steady State Free Presession (bSSFP)





- Summation of all the gradients along each direction is zero.
- TE is balanced at TR/2.
- Transmission RF phase is alternating between 0° and 180°.
- High flip angle (40–70°), short TR (3–5ms), but relatively high SNR
- Good for fast imaging (e.g. ALADDIN, cardiac MRI, fMRI)